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The DOE CBNP Salt Lake City URBAN2000 Experiment

Data Report on the LANL Urban Wind and Temperature Measurements

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I Introduction

The field measurement program that took place in Salt Lake City, Utah and the Salt Lake Valley during October 2000 comprised two component programs designed to study atmospheric transport and dispersion at scales from building scale to urban scale to mesoscale. The program focussed on the building-to-urban scale was known as URBAN2000 and was sponsored by the U.S. Department of Energy (DOE) Chemical and Biological National Security Program (CBNP) within the Office of Nonproliferation Research and Engineering. The program component addressing the larger scale in a region of complex terrain is known as the meteorological study of atmospheric Vertical Transport and Mixing (VTMX) and was sponsored by the DOE Environmental Meteorology Program in the Environmental Sciences Division, Office of Biological and Environmental Research of the Office of Science.

This report is a detailed chronicle of the participation of Los Alamos National Laboratory (LANL) in URBAN2000 in Salt Lake City in October 2000. A complete description is given of our instrumentation, experimental layout, and experimental procedures. A complete listing and graphical presentation of the data available to other researchers is given. To provide context for the reader, this introductory section provides a brief description of the objectives of and participants in the two component programs. Sections II and III give brief synopses of the instrumentation deployed, locations, and measurements made by other participants in the VTMX experiment and the URBAN2000 experiment, respectively. Section IV provides detail on the LANL instrumentation, deployment and measurements made. Section V discusses instrument calibration and data quality control. Some sample data and simple analyses involving time-averaging are given in Section VI. Appendix A contains sonic anemometer calibration data and Appendix B contains thermistor calibration data. Appendix C contains plots of the processed data and a listing of the data files. In this context processed data refers to raw data to which calibrations have been applied and data exceptions have been deleted or replaced.

URBAN2000 was a large-scale urban meteorology and dispersion field program. Data from URBAN2000 will lead to a better understanding of flow and transport phenomena in cities and will allow evaluation and validation of simulation models being developed under the auspices of the CBNP Program. Project leadership was shared by Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Pacific Northwest National Laboratory. Numerous other institutions participated and provided special expertise. These included the NOAA Air Resources Laboratory/Field Research Division, DERA (UK Ministry of Defense), Dugway Proving Ground, Vaisala Corporation, Litton Industries, Coherent Technologies, and Brookhaven National Laboratory.

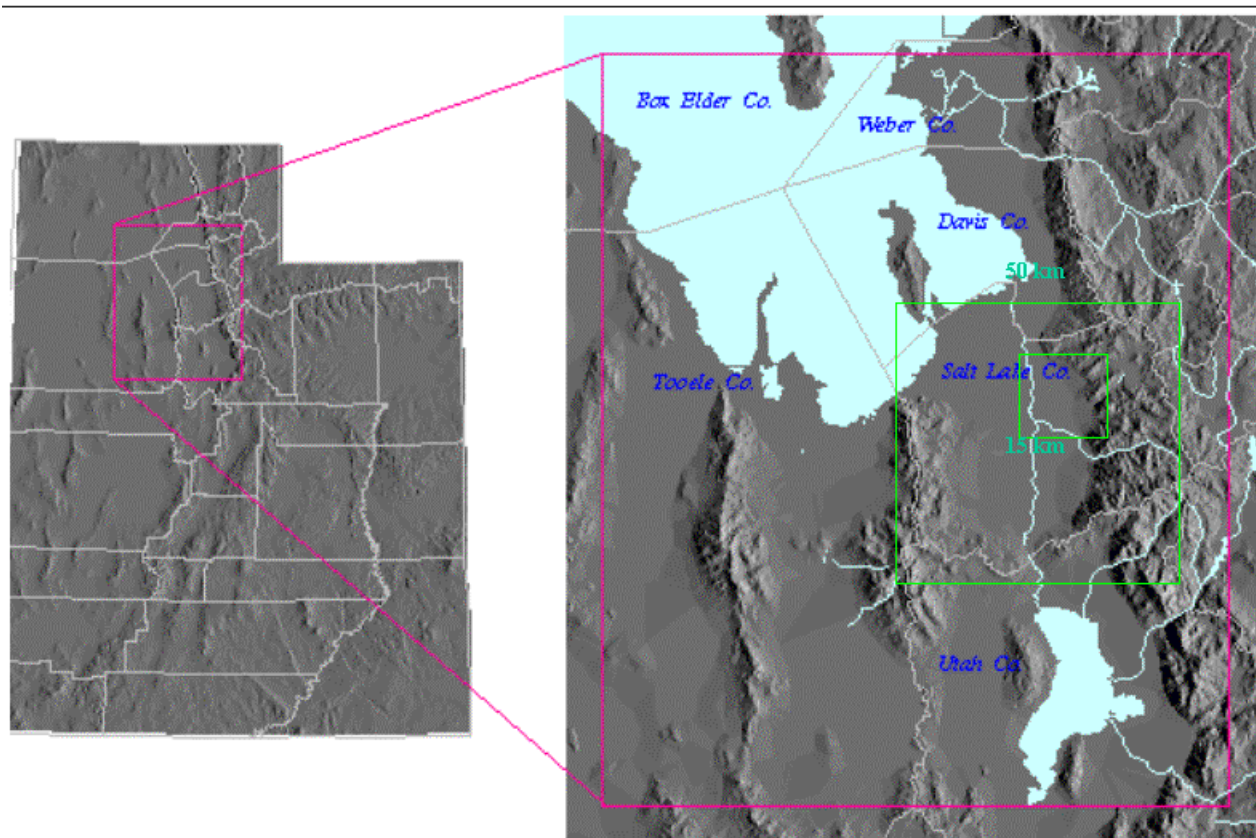


Figure 1. Utah and the north-central Region

The 15 km rectangle is centered on Salt Lake City and defines the area of interest for URBAN2000. The 50 km rectangle denotes the VTMX study area.

URBAN2000 had equal emphasis on meteorology and dispersion. Meteorological instrumentation deployed in downtown Salt Lake City included 60 temperature data loggers, 15 2-D sonic anemometers, 8 3-D sonic anemometers, a doppler lidar for continuously mapping winds, a ceilometer, an acoustic sodar, and additional fixed point and mobile temperature sensors. Some of this instrumentation was deployed continuously through most of the month and some was deployed only during intensive operations periods (IOPs) during which tracer release and sampling occurred.

Six full-scale IOPs (all at night) were run during URBAN2000. Each involved the near-ground release of sulfur hexafluoride (SF_6) tracer gas and the release of perfluorocarbon tracers (PFTs). One PFT was released at the SF_6 release site and one was released from the top of a nearby parking garage. Tracer samplers were distributed to resolve the various scales-of-motion being studied. For the building-scale, 45 SF_6 samplers were located around and in the near-vicinity of 2 buildings in downtown SLC. For the downtown-scale, 64 SF_6 /PFT samplers were located

in a 5-block-by-5-block square area (25 blocks) of downtown SLC, and 36 SF₆ samplers were located around SLC extending 6 km from the SF₆ release location. Four instrumented vans with fast-response (1 Hz) SF₆ analyzers were driven along arcs at radii of 1, 2, 4, and 6 km from the release to provide real-time plume tracking.

The larger-scale VTMX experiment had its own specific set of goals, but URBAN2000 received the benefit of a high density of measurements of larger scale atmospheric processes that influence the urban scale. VTMX involved the collaboration of scientists from government laboratories, universities, and private industry to carry out studies of the processes contributing to the vertical transport and mixing of momentum, heat, and water vapor in the lowest kilometer or two of the atmosphere. Such processes affect how wind speed, temperature, and moisture vary with height and how atmospheric pollutants may be distributed over an area. The current ability to describe or model many of the phenomena relevant to vertical transport and mixing is limited when conditions of light winds and weak atmospheric turbulence are present - conditions that frequently occur at night or during stagnant weather periods during the winter. The VTMX program concentrated on examining such periods in an effort to increase the fundamental understanding of these phenomena, which may eventually lead to improvements in air quality and weather forecasting models.

Participants included researchers from the following institutions:

Department of Energy:	University of Utah
Argonne National Laboratory	University of Massachusetts
Brookhaven National Laboratory	Oregon State University
Los Alamos National Laboratory	Stanford University
Pacific Northwest National Laboratory	Arizona State University
National Oceanic and Atmospheric Administration:	Desert Research Institute
(NOAA)	Colorado Research Associates
Environmental Technology Laboratory	National Center for Atmospheric
Atmospheric Turbulence and Diffusion Division	Research

The Salt Lake Valley (see Figure 1) was chosen as a study site for a number of reasons. The surrounding mountains often contribute to the development of cold pools, i.e., conditions in which colder air is trapped in the valley while warmer air (defined by virtual potential temperature) is found at higher elevations. Vertical transport and mixing processes in these conditions can be particularly difficult to describe. Flows over the mountains and out of the canyons and winds generated by the temperature contrasts between the Great Salt Lake and the valley floor may generate wind shear and atmospheric waves; these, in turn, can modify the vertical structure of the atmosphere's properties. The terrain also imposes some limitations on the possible wind patterns in the area, an effect that is useful in identifying suitable sites for possible instrument deployment.

The University of Utah's meteorology department provided a valuable resource for assistance in planning and designing the experiment and in analyzing the data to be collected.

Researchers deployed a variety of instruments to probe the atmosphere's behavior during the measurement program, including Doppler radars, sodars, lidars, instrumented balloons, sonic anemometers, atmospheric tracers, and an instrumented aircraft. Many measurements were made continuously throughout the experimental period, but additional instruments were deployed and operated during 10 IOPs. As in URBAN2000, the IOPs were the tracer release and sampling periods. Scientists will use the data collected to determine the mean and fluctuating wind, temperature, and moisture patterns over the Salt Lake Valley, and to develop an understanding of the dynamical processes in the atmosphere. They will then test the ability of various computer models to simulate these processes, and to identify necessary improvements in cases where the models' performance is unsatisfactory.

II VTMX Overview

The Department of Energy's (DOE) Vertical Transport and Mixing (VTMX) program sponsored a major meteorological and tracer field campaign in the greater Salt Lake City basin during October 2000¹. Investigators from government laboratories and universities are investigating meteorological and fluid dynamical processes governing the transport and mixing of momentum, heat, water vapor, and air contaminants within the lowest kilometer or two of the atmosphere. The VTMX program is supported by the Office of Biological and Environmental Research's Environmental Meteorology Program.

The VTMX field campaign efforts in Salt Lake City during October 2000 were designed to address in a coupled fashion vertical exchange processes and atmospheric dispersion over scales of motion ranging from turbulent eddies to circulations on the scale of the Salt Lake Basin. A map of the primary VTMX sites is shown in Figure 2. The VTMX instrumentation deployed during October 2000 included 6 radar profilers, 5 acoustic sodars, 3 rawinsonde balloon systems, 4 tethered-balloon systems, a Doppler lidar, and a network of meteorological stations, temperature data loggers, and sonic anemometers. Most of the remote profiling instruments continuously measured meteorological quantities throughout the month. The other meteorological systems and a series of tracer systems operated only during intensive field operation periods (IOPs). The 10 IOPs conducted during the month are listed in Table 1. The listing of SF₆ tracer is specific to the URBAN2000 experiment. In the month of October, Salt Lake City operates on Mountain Daylight Time (MDT). MDT is six hours earlier than UTC. Thus an IOP started at 22 UTC was started at 1600 (4 pm) MDT.

Investigating vertical exchange processes in stable atmospheric conditions during the night and morning transition periods was the primary VTMX objective and therefore the focus of the IOPs. Radar profiler/radio acoustic sounding systems and acoustic sodars were deployed at the ANL site and at the two PNNL sites to continuously measure profiles of wind and temperature. A Turbulent Eddy Profiler (TEP) and an S-band FMCW (frequency modulated continuous wave) profiler were deployed at the UM site. TEP provides a four-dimensional (a 3-D volume plus time) view of atmospheric turbulence structure within a volume of the boundary layer at spatial resolutions comparable to large eddy simulations and the FMCW radar is designed to complement TEP by providing finer resolution profiles through the TEP volume. NCAR deployed a multiple antenna wind profiler radar that points continuously in the vertical direction allowing, in contrast to typical Doppler-based systems, a continuous measure of the vertical motion. Profiles of wind

1. Doran, J. C., J.D. Fast, and J. Horel, "The VTMX 2000 Campaign," Bulletin of the American Meteorological Society (in press, April 2002).

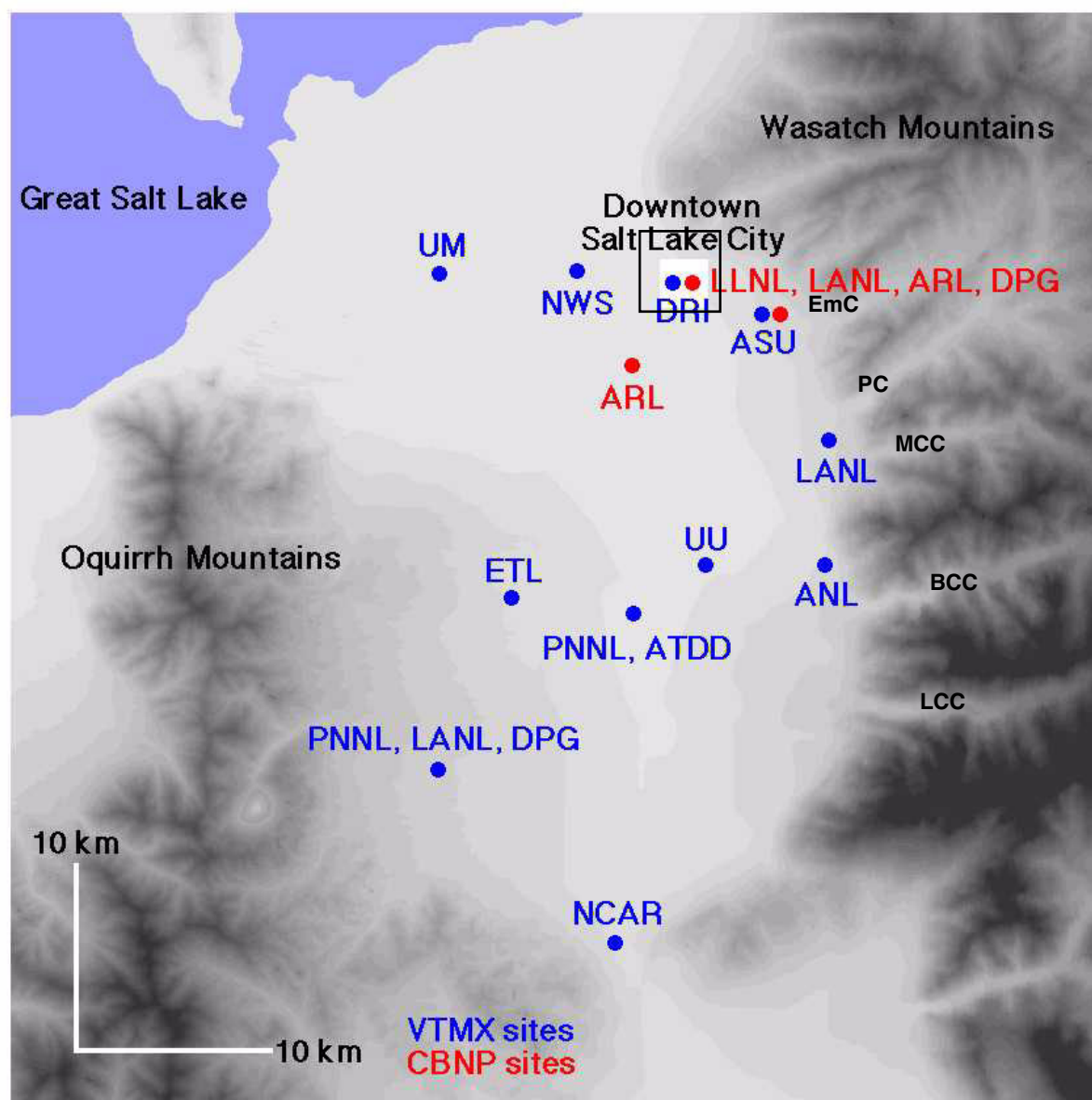


Figure 2. Primary VTMX and CBNP Sites During the October 2000 Field Campaign

ANL - Argonne National Laboratory

ARL - NOAA Air Resources Laboratory

ASU - Arizona State University

ATDD - NOAA Atmospheric Turbulence & Diffusion Division

DPG - Dugway Proving Grounds

DRI - Desert Research Institute

ETL - NOAA Environmental Technology Laboratory

PC - Parley's canyon

MCC - Mill Creek Canyon

LCC - Little Cottonwood canyon

Figure credit: www.pnl.gov/atmos_sciences/Jdf/design.html

LANL - Los Alamos National Laboratory

LLNL - Lawrence Livermore National Laboratory

NCAR - National Center for Atmospheric Research

NWS - National Weather Service

PNNL - Pacific Northwest National Laboratory

UM - University of Massachusetts

UU - University of Utah (Wheeler Farm site)

EmC - Emmigration Canyon

BCC - Big Cottonwood Canyon

and temperature were obtained from rawinsondes released at the UU (22, 23, 00, 01, 03, 05, 07, 09, 12, 13, 14, 15, 16 UTC) and NCAR (00, 03, 05, 07, 09, 12 UTC) sites during the IOPs. The NWS also released rawinsondes at 05 and 09 UTC, in addition to the standard ones at 00 and 12 UTC. Tethered-balloon systems were used at the ASU, NCAR, and PNNL (southwestern basin) sites to measure high-resolution wind and temperature profiles within a few hundred meters of the ground periodically during each IOP. ETL operated a lidar during the IOPs for mapping the 3-D winds across the basin and characterizing the major canyon flows that may interact with the flows in the Salt Lake basin. The LANL volume imaging, scanning, high-resolution Raman water vapor-temperature lidar was deployed at the southwestern PNNL site. The Long-EZ aircraft also flew during a few of the IOPs measuring meteorological and turbulence quantities across the Salt Lake basin. Three-dimensional sonic anemometers were deployed at the ASU (6, 16 m), NOAA/ATDD (2, 5, 10, 20 m), UM (3 m) and both PNNL (9 m) sites to measure turbulence and flux profiles.

Table 1: Intensive Operation Periods (IOPs) During the VTMX Field Campaign

IOP #	Period	Type
1 *	22 UTC [#] 2 October - 14 UTC 3 October	meteorology
2 *	22 UTC 6 October - 16 UTC 7 October	meteorology, PFT and SF ₆ tracers
3	22 UTC 7 October - 04 UTC 8 October	meteorology
4 *	22 UTC 8 October - 16 UTC 9 October	meteorology, PFT and SF ₆ tracers
5 *	22 UTC 14 October - 16 UTC 15 October	meteorology, PFT and SF ₆ tracers
6	22 UTC 16 October - 16 UTC 17 October	meteorology
7 *	22 UTC 17 October - 16 UTC 18 October	meteorology, PFT and SF ₆ tracers
8	22 UTC 19 October - 16 UTC 20 October	meteorology and PFT tracer
9 *	04 UTC 21 October - 12 UTC 21 October	meteorology, SF ₆ tracer
10 *	22 UTC 25 October - 14 UTC 26 October	meteorology, PFT and SF ₆ tracers

* Indicates that an URBAN2000 IOP was carried out at the same time.

[#] During the month of October Salt Lake City was on Mountain Daylight Time (MDT). The conversion is MDT = UTC - 6 hrs.

Six tracer experiments, utilizing four different perfluorocarbon tracers (PFTs) released simultaneously at four different sites, were carried out during the meteorological IOPs. Two PFTs were released downtown near the corner of State Street and 400 South, one at the surface and the other

from the top of a nearby parking garage. By releasing the tracers at two heights some information on the effect of both upwards and downwards mixing resulting from vertical wind shears and turbulence will be obtained. A third PFT was released near the mouth of Parley's Canyon (PC) at the LANL site. This tracer could follow the downward slope of the ground or it could become elevated above the cold pool in the basin. It is expected that the interaction of the downslope flows from the Parleys-Emmigration Canyon complex and the down-valley flows will affect vertical exchange processes in the basin. The fourth PFT was released from Wheeler Farm (WF), closer to the center of the basin, to track down-valley flows. The PFTs at WF and PC were released at a constant rate beginning at 23 MDT (05 UTC) and continuing for eight hours while the PFTs downtown were released beginning at 01 MDT (07 UTC) and continuing for six hours. The PFT releases were stopped before the morning transition period so that only the nocturnal tracer plumes were tracked.

PFT samples were collected at 50 sites throughout the basin using the Brookhaven Atmospheric Tracer Samplers (BATS). Two-hour samples were collected sequentially through the sampling period that extended from the release start (23 MDT) through the night until the next afternoon (13 MDT). Most of the samplers were located on power or light poles about 3 m above the ground. The rest of the PFT samplers were co-located at the main VTMX sites, mesonet sites, CBNP sites, or other meteorological sites supported by this project. 350 PFT samples were collected during each tracer IOP for a total of 2100 samples during the month of October. In addition to the 50 tracer samplers deployed during the experiments, 4-hour samples were collected at six sites. The sample analysis is being done at Brookhaven National Laboratory.

Web sites with extensive information on VTMX include:

http://www.pnl.gov/atmos_sciences/Jdf/vtmxproject.html and

<http://www.met.utah.edu/vtmx/>.

III URBAN2000 Overview

The URBAN2000 tracer and meteorological experiments were conducted during October 2000 and provide a unique set of night-time atmospheric dispersion data covering transport scales from individual buildings on through the urban-scale to the regional-scale¹. The URBAN2000 researchers collaborated closely with DOE's Environmental Meteorology Program by adding building-scale through urban-scale experiments (URBAN2000) to their regional-scale Vertical Transport and Mixing experiments (VTMX) in the greater Salt Lake City area.

Meteorological measurement and tracer sampling instruments were installed throughout Salt Lake City and operated for the month of October 2000 for the URBAN2000 field campaign. Instruments were sited to resolve scales of motion ranging from flows around individual buildings in downtown Salt Lake City to flows throughout the urban area. The scale of the URBAN-2000 experiment may be seen in Figure 3 in which the outer 6 km arc was the boundary for fixed sampler boxes and one of the plume-chasing vans. The blue hatched area is the 5-block by 5-block focus area for which more detail is shown in Figure 4. The meteorological instrumentation shown was operated more or less continuously for the entire month. The samplers were deployed prior to an IOP and collected at the end of the sampling period. The central experimental site is shown in Figure 5. The mobile van, GC, IR, LLNL sonic anemometers (see Figure 5), and all sampling instrumentation (denoted in yellow in Figure 5) were deployed only during the IOPs.

Locations and brief descriptions of much of the instrumentation deployed for URBAN2000 are given in Figures 3-5. However, further mention should be made of the six NOAA vans equipped with fast response gas chromatographs for SF₆ detection (see Figure 6). Four of the vans did plume chasing during the IOPs roughly following 1, 2, 4, and 6 km arcs to the NW of the release site. Two vans remained at fixed locations, one of which is seen in Figure 5 and labeled NOAA mobile unit. During IOPs 2 and 4, Litton Industries deployed a van with a volume scanning FTIR spectrometer. This was used relatively near the release site to map the vertical extent of the SF₆ plume. For a little under two weeks, Oct. 19 at 1800 MDT until Oct. 27 at 1100 MDT, Coherent Technologies Incorporated deployed a wind-tracer doppler lidar at a site 4 km east of downtown and approximately 400 m higher than downtown. These dates covered IOPs 8-10. This unit mapped out the radial component of the wind in three dimensions over the city and up nearby canyons. This work was partially sponsored by the Army Research Office.

1. Allwine, K. J., J. H. Shinn, G. E. Streit, K. L. Clawson, and M. J. Brown, "Overview of URBAN 2000: A Multi-Scale Field Study of Dispersion Through an Urban Environment," *Bulletin of the American Meteorological Society* (in press, April 2002).

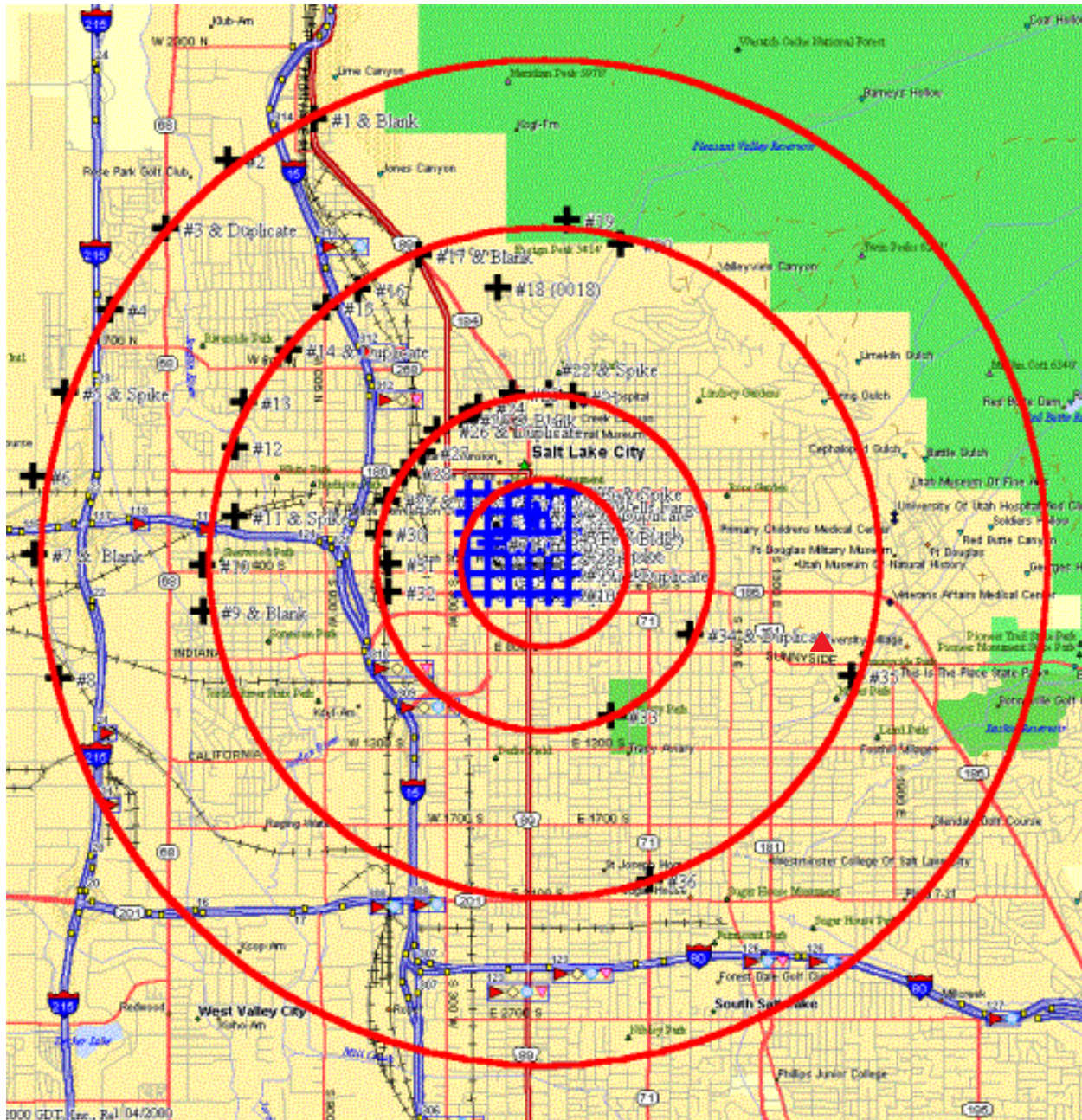


Figure 3. Location of the URBAN2000 Experiment

The red circles are 1, 2, 4, and 6 km from the central experimental site. The blue hatched area is the 5-block square urban focus area. The black crosses are fixed tracer sampler locations. Plume-chasing vans (NOAA) with real-time SF_6 detection instrumentation drove back and forth roughly on the 1, 2, 4, and 6 km arcs to the NW of the tracer release site throughout all of the URBAN2000 IOPs except the first. The red triangle marks the Arizona State University VTMX site.

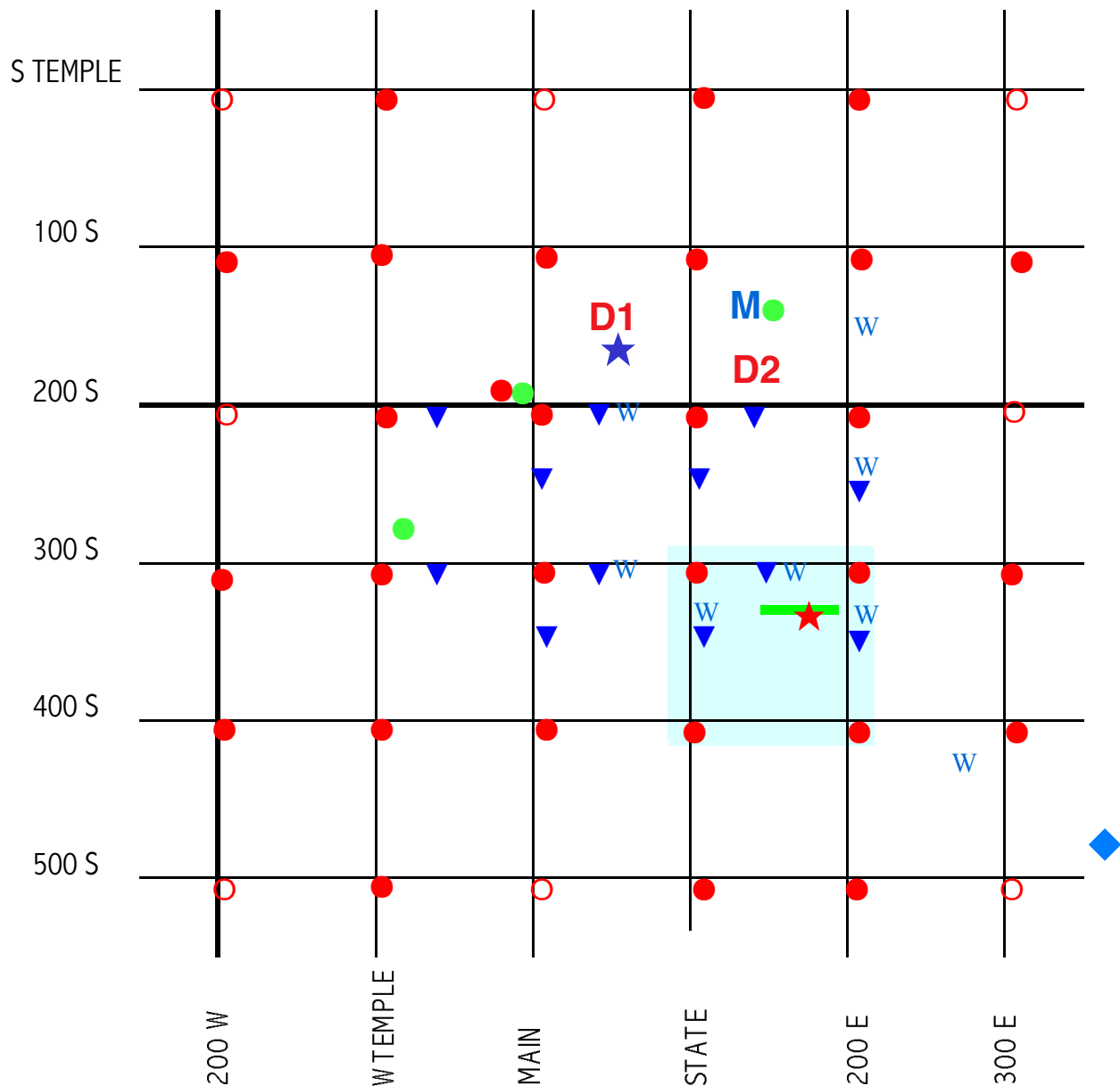


Figure 4. Detail of the 5-block square focus area.

- W** Dugway surface wind stations
- NOAA PFT/SF₆ 1/2-hr samplers (an elevated or rooftop location)
- NOAA PFT/SF₆ 1-hr samplers
- ▼ NOAA SF₆ 1/4-hr samplers
- ★ PFT point release (elevated)
- NOAA PFT/SF₆ 1/2-hr samplers
- ★ PFT point release (surface)
- SF₆ release (point or line) at the surface
- D1** UK-DERA 3-D sonic anemometers (2 on one tower) on top level of parking structure
- D2** UK-DERA 3-D sonic anemometers (2 each on two towers) on top level of parking structure
- M** 2-D sonic anemometer (LANL) and minisodar (Dugway) on the roof of the Federal Building
- ◆ One Dugway 3-D and two LLNL 2-D sonic anemometers on a 20 m boom

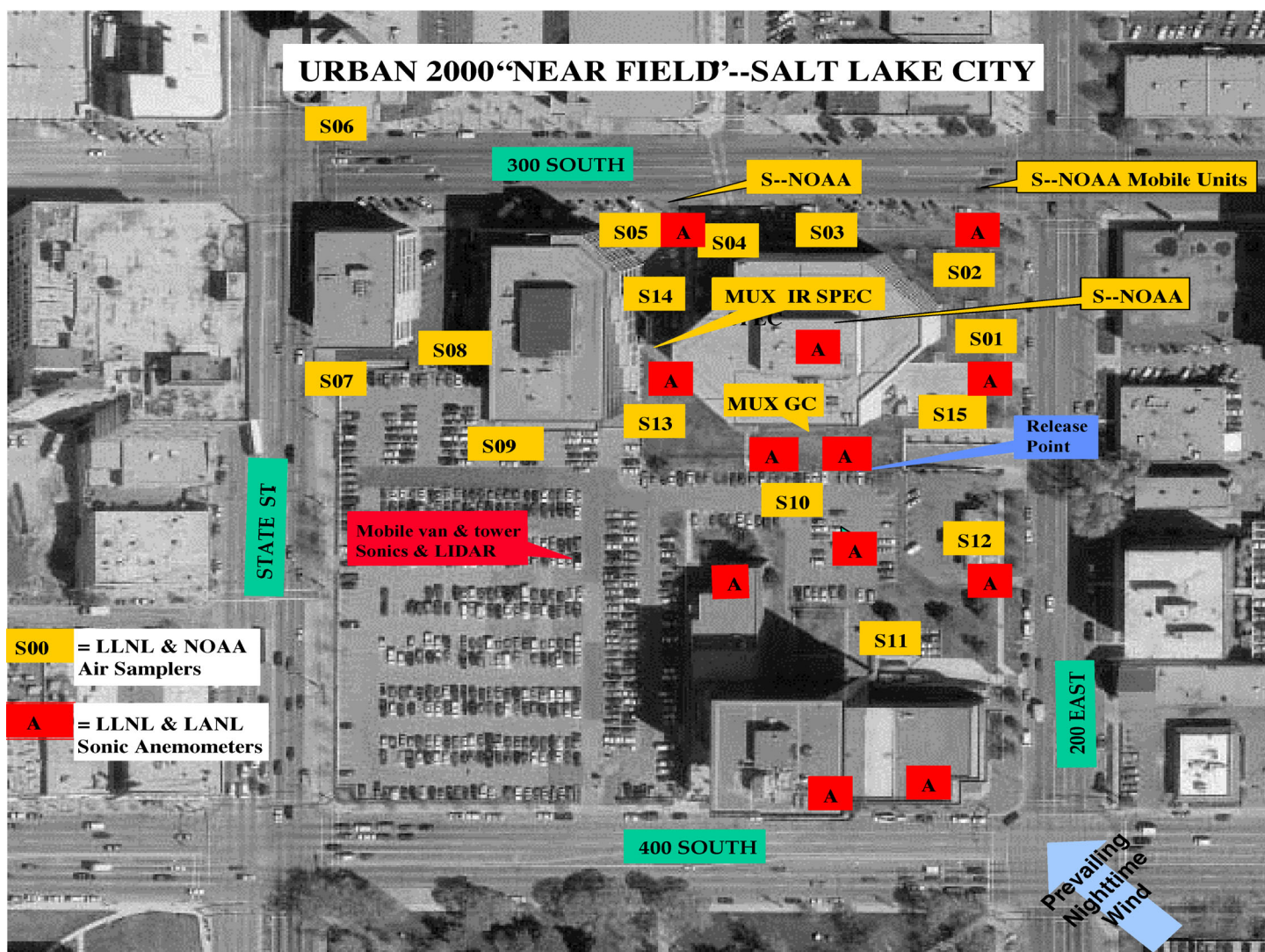


Figure 5. Overhead view of central experimental site.

The building at the corner of 400 South and 200 East is the City Centre Building. To the north is the Heber-Wells State Office Building. The anemometers most closely surrounding the Heber-Wells Building and the unit just south of S12 are LLNL 2-D sonic anemometers deployed (at the surface on 2.5 m tripods) during each IOP. The other anemometers, 3 on the City Centre roofs, one on the Heber-Wells roof, and a unit mounted on a light pole in the parking lot (in the middle of S10, S11, and S12) are LANL 2-D sonic anemometers deployed for most of the month of October. The MUX IR and MUX GC are LLNL infrared spectrometer and gas chromatograph units with multiplexed inputs for real-time or near real-time SF_6 detection. The mobile van is a LLNL RV, deployed during IOPs, with a 10-meter tip-up tower. Two NOAA 3-D sonics were mounted on the tower. The lidar is a Vaisala ceilometer, also deployed during IOPs, on loan courtesy of Vaisala Corporation.

Table 2: URBAN2000 IOP Details

IOP #	Start Time*		SF ₆ Source Geometry	SF ₆ release start time (MDT)			Sampling end time (MDT) (start day +1)	Comments
	UTC	MDT		Release 1	Release 2	Release 3		
1	2-Oct-00 2200	2-Oct-00 1600	Point	0100 (2g/s)	0300 (1g/s)		0500	Shakedown; met, mux GC, mux IR, and 2 mobile vans deployed. No SF ₆ box samplers & no PFTs.
2	6-Oct-00 2200	6-Oct-00 1600	Line, 1g/s	0100	0300	0500	1300	Full met, SF ₆ , and PFT experiment, low winds.
3	7-Oct-00 2200	7-Oct-00 1600						VTMX only.
4	8-Oct-00 2200	8-Oct-00 1600	Line, 1g/s	0100	0300	0500	1300	Full met, SF ₆ , and PFT experiment, low winds.
5	14-Oct-00 2200	14-Oct-00 1600	Line, 1g/s	0100	0300	0500	1300	Full met, SF ₆ , and PFT experiment, low winds.
6	15-Oct-00 2200	15-Oct-00 1600						VTMX only.
7	17-Oct-00 2200	17-Oct-00 1600	Line, 1g/s	0100	0300	0500	1300	Full met, SF ₆ , and PFT experiment, low winds.
8	19-Oct-00 2200	19-Oct-00 1600						VTMX & URBAN PFT experiment. No met or SF ₆ .
9	21-Oct-00 0400	20-Oct-00 2200	Point, 2g/s	2200	0000	0200	0400	Full met & SF ₆ experiment, higher winds. No PFT.
10	25-Oct-00 2200	25-Oct-00 1600	Point, 1g/s	0100	0300	0500	1300	Full met, SF ₆ , & PFT experiment, low to higher winds.

Notes

* time of first balloon launch by VTMX

- 1) met refers to those instruments deployed just for the IOP
- 2) met, mux GC, and mux IR were taken down within 1 hr after the end of final release
- 3) URBAN PFT point source releases (see Fig. 4) were continuous from 0100-0700 (MDT)
- 4) URBAN utilized two different PFTs, one at each source location

Time Conversion

MST	MDT	UTC
current	+1hr	+7hr
-1hr	current	+6hr
-7hr	-6hr	current

Table 2 gives detail about the shakedown IOP and six full-scale URBAN2000 IOPs that were nested within the ten VTMX IOPs. Time-integrated tracer samples (nominally 5-minute to 2-hour integration times) were collected by 200 samplers located throughout the Salt Lake Basin. The sampling period extended from just before tracer release start (~2300 MDT) through the night until the next afternoon (~1300 MDT). The tracer samplers were distributed with the intent to resolve the various scales-of-motion being studied. Forty-five SF₆ samplers were located around the downtown study buildings (three at each of the S01-S15 sites in Figure 5), 40 combined SF₆/PFT samplers and 24 SF₆ samplers were located in a 5-block-square area (25 blocks) of downtown (see Figure 4), 36 SF₆ samplers were located on three sampling arcs (2-, 4-, and 6-km) to the northwest of the downtown SF₆ release location (see Figure 3), and 55 PFT samplers were located throughout the Salt Lake Basin. A total of nearly 11,000 SF₆ samples and 5,000 PFT samples were collected during the tracer experiments. In addition to the 200 time-integrated tracer samplers deployed during the combined VTMX/URBAN2000 experiments, two multiplexed SF₆ analyzers (one IR spectrometer sampling at 5 second intervals and one gas chromatograph sampling at approximately 2 minute intervals) were deployed by LLNL during the IOPs around the downtown study building.

A summary of meteorological instrumentation deployed for URBAN2000 follows.

- Building scale (completely within the core block): 12 2-D sonic anemometers (the five long-term locations included temperature measurements), 2 3-D sonic anemometers, and 1 laser ceilometer
- Urban scale (a 5-block by 5-block square): 10 portable meteorological stations, 3 2-D sonic anemometers (1 station included temperature), 7 3-D sonic anemometers, and 1 acoustic sodar
- 1 to 6 km scale: 6 wind stations, 2 acoustic sodars, 1 radar wind profiler, 54 temperature loggers, 1 Doppler lidar

The PNNL temperature loggers were sited on a north-to-south transect and on a west-to-east transect across Salt Lake City collecting 15-minute-average data for the month of October. They were located on 400 South from 1500 West to 1500 East, and on State from 1500 South to approximately 1500 North, so they crossed the urban scale and building scale regimes.

The Arizona State University VTMX site (<http://vtmx.eas.asu.edu/vtmx/>) included a variety of surface, tower, and tethered balloon meteorological measurements and lay well within the 6 km radius-of-interest of the URBAN2000 campaign (see Figure 3).



Figure 6. NOAA Mobile SF₆ Detection Unit

Vans are equipped with Scientech TGA-4000 SF₆ analyzer operated at 4Hz and a GPS unit. The sample port is at approximately 2m height.

IV URBAN2000: The Los Alamos National Laboratory Effort

LANL deployed and operated six meteorological stations in downtown Salt Lake City during the month of October as part of the DOE-funded URBAN2000 experiment. The stations recorded horizontal wind direction and speed as well as temperature measurements at two heights above the surface. The wind measurements, taken every second, provide data to help us understand the complexities of air circulation around buildings and of turbulence generated as incoming winds impact buildings. The temperature measurements may provide information about local stratification and about heat fluxes from urban surfaces, important aspects of micrometeorology in cities. Los Alamos researchers also conducted a series of urban heat island measurements: recording temperature while traversing different zones of the city from the high-density core to suburban semi-rural regions. In an effort related to understanding and then parameterizing solar and thermal radiation behavior in urban areas, Los Alamos researchers also conducted a study of sky view factors in collaboration with the University of Indiana. The urban heat island and sky view factor studies will be briefly summarized later in this section. More detail may be obtained in separate reports.^{1 2}

The wind sensor instruments deployed by LANL are Handar (now Vaisala) model 425A Ultrasonic Wind Sensors (2-D). These were used in conjunction with the Handar 555C Data Acquisition System with the expanded memory module. The optional expanded memory module is an internal option to write data to a PCMCIA memory card. The PCMCIA card may be removed from the 555C unit and inserted into the PCMCIA slot of a laptop computer. The data may then be downloaded, the card reformatted, and replaced into the 555C to continue the data-logging process. Two thermistors, each mounted in a naturally ventilated radiation shield, were installed at each station. The exception was Unit 500 (Green) for which no shields were used. The thermistors were Omega ON-405-PP air temperature sensors in which the epoxy-encapsulated thermistor is surrounded by a stainless steel cage. The calibration standard and the thermistor used for the urban heat island measurements was a YSI 4600S precision thermometer, calibrated and traceable to NIST. More detailed specifications of the instruments is found in the next section on instrument calibration.

Figure 7 is an overhead photograph of the instrumented section of downtown Salt Lake City with an “X” denoting each station location. Due to the slanted perspective of the photograph, an

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1. Brown, M. and E. Pardyjak, 2001: “Temperature measurements for investigation of the Salt Lake City Urban Heat Island - Data Report for the DOE CBNP URBAN2000 Field Experiment, Oct. 2000”, LA-UR-01-3176
 2. Brown, M. and S. Grimmond, 2001: “Sky View Factor Measurements in downtown Salt Lake City - Data Report for the DOE CBNP URBAN2000 Field Experiment, Oct. 2000”, LA-UR-01-1424

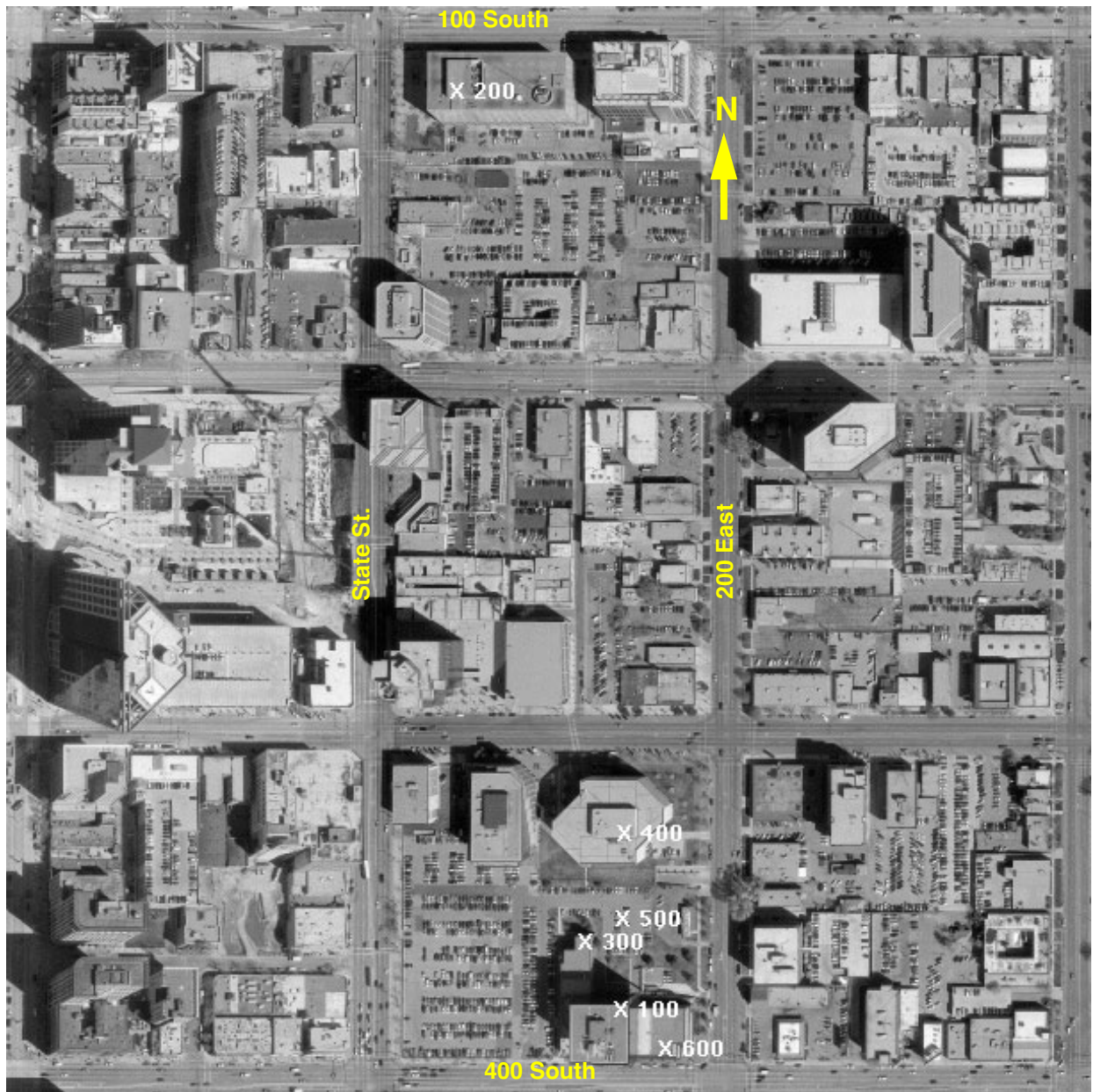


Figure 7. Location of Los Alamos Meteorological Monitoring Stations

An “X” marks the location of each station. The numbers are unit identifiers. The City Centre Building has units 100, 300, and 600, the Heber-Wells Building has unit 400, and the Federal Building has unit 200. Unit 500 is on a light pole in the parking lot. North is to the top of the picture.

accurate coordinate location cannot be obtained from the photo. Table 3 gives details about the location and heights of the sensors. The location and height data is from an urban terrain and building database supplied to us (under joint subcontract to LANL and LLNL) by Urban Data Solutions, Inc. of New York City. The Los Alamos stations are identified by a color and a number. Unit 100 (White) was located on the main roof (10 stories) of the City Centre Building at the corner of 400 South and 200 East. Unit 400 (Red) was located on the penthouse rooftop (7 stories) on

Table 3: Detailed Location Data for LANL Meteorological Stations
(listed from south to north)

Station ID	Location Descriptor	Ground Elevation (m)	Roof top Elevation (m)	Height above Rooftop (m)	
				Anemometer	Temperature1 Temperature2
600(Orange)	City Centre east wing	1301.0	1314.6	3.60	0.60 2.00
100(White)	City Centre rooftop	1301.0	1341.2	3.44	0.59 1.77
300(Yellow)	City Centre north wing	1301.0	1314.6	3.46	0.59 2.00
500(Green)	City Centre parking lot light pole	1301.0	N/A*	3.81	2.6 2.6
400(Red)	Heber-Wells penthouse	1303.5	1338.1	3.47	0.60 2.00
200(Black)	Federal Building penthouse	1313.2	1356.0	3.45	0.60 2.00
• Heights for Unit 500 are above the ground.					
Station ID	UTMX (m)	UTMY (m)	Latitude (N)	Longitude (W)	
600(Orange)	425232	4512597	40° 45' 39.4"	111° 53' 9.0"	
100(White)	425212	4512628	40° 45' 40.4"	111° 53' 9.8"	
300(Yellow)	425180	4512665	40° 45' 41.6"	111° 53' 11.2"	
500(Green)	425200	4512678	40° 45' 42.0"	111° 53' 10.4"	
400(Red)	425212	4512743	40° 45' 44.1"	111° 53' 9.9"	
200(Black)	425105	4513235	40° 46' 00.0"	111° 53' 14.7"	
Note: UTM location is North Zone 12. All location coordinates are in NAD83.					

the Heber-Wells State Office Building at the corner of 300 South and 200 East. Unit 300 (Yellow) was located on the roof of the north wing of the City Centre Building. Unit 600 (Orange) was located on the roof of the east wing of the City Centre Building. The north and east wings of the City Centre are each three stories high. While the unit to the east could sample the southeast winds that predominate at night, it was anticipated that both of the lower units would be affected by building-induced circulation and would thus provide data to understand such circulations and to test and validate fluid dynamics models. Unit 500 (Green) was mounted on a light pole in a parking lot immediately between the City Centre and Heber-Wells buildings. This unit, too, would be in the zone of building-induced circulations. All five of these units were on the western side of the core experimental block. Unit 200 (Black) was two blocks to the north on the penthouse rooftop (9 stories) of the Federal Building at the corner of State Street and 100 South. This location was on the eastern half of the block. The line drawings in Figures 8 - 10 give information on rooftop placement.

In Figures 11a,b - 16a,b are a series of photographs taken at each station to provide a picture of the surrounding fetch. The photographs were taken at every 45° of the compass, that is N, NE, E, etc. The photographs are labelled by the direction the photographer is facing. So north means the photographer is standing on the south side of the station facing north. Hence, a “north” photograph shows the obstacles (or fetch) that would influence a northerly wind at that sensor.

Post-experiment we discovered that we had had serious problems with the frequency of data recording with the Handar dataloggers. We had programmed each datalogger to record six data values (wind speed, wind direction, u and v components of the wind vector, and two temperatures) at a frequency of 1 Hz. To provide extended operation time we had equipped each datalogger with the Handar extended memory module, a plugin card that powers and controls I/O for a PCMCIA SRAM card. We used 2Mb SRAM cards, providing enough memory for nearly two days of operation. Though the datalogger has an internal clock, it does not record a time stamp with each data record. Rather the start time and the sampling frequency are written in each data file header and then a presumed time is recreated for each data record when the data files are unpacked. If there are more or less data records than expected based on the programmed sampling frequency, labelled time becomes shifted from real time and there is no way, within any given data file, to re-establish the absolute time of each data record.

Extensive post-experiment testing revealed two datalogger problems when using the SRAM cards. The more serious problem affected four of the six units; those being 100, 200, 400, and 600. In the range of seven to ten hours after the start of a logging session it seems that writing data to the SRAM card could not keep up with the sampling frequency. The logger begins to write

fewer and fewer data points per hour until at 20-22 hours into the session it is recording only about two out of three measurements. The other problem affects all six units and is a seemingly random stop of recording for 14 seconds followed by an over sampling (or double writing) in the next several minutes that actually results in a few too many data points.

Each box had a repeatable pattern. These tests were done with a new program that recorded a time stamp for each data record, but recorded only the same total number of bytes per record as we had recorded in Salt Lake City. For these tests, we began each logging session with an empty and reformatted SRAM card as was done in SLC. For the first six hours of logging the six instruments showed very similar behavior. In a given hour there would be several periods of data dropout, i.e., no data recorded for as much as 14 seconds. Then in the next couple of minutes following the data dropout there would be oversampling (or double recording) with the net result being an excess of an average of 3 records per hour (range 0 to 7). Though the net result is close to the correct number of records per hour, the data is no longer synchronized to the second because of the pattern of dropped data followed by excess recording.

In the six to nine hour period five of the instruments (all but unit 100) continued as described above, but the net oversampling dropped to an average of 0-2 per hour. Unit 100, unfortunately, was not consistent and on one of three tests showed a significantly higher data dropout rate such that by hour nine it was several hundred data records short. Following hour nine, units 300 and 500 maintained the logging behavior just described, but all the other units began a pattern of increasing data dropout such that by hour twenty-two they were recording at about 2/3 of the programmed frequency. The data dropout pattern also changed from 14 second gaps followed by oversampling to just skipping about one out of every three readings.

Based on these findings we are presently releasing only the first six hours of data from any logging session for the four sensors White(100), Black(200), Red(400), and Orange(600).

After six hours of measurement the overrecording rate on the Yellow(300) and Green(500) units drops to an average of 0-2 per hour so the additional cumulative error for the full measurement period is small and the data files from these units are being released in their entirety.

The data within a given file can be analyzed for the mean wind and turbulence statistics, but the files cannot be compared one to another on a second-by-second basis because of the data recording problem described above and because we did not consistently follow the procedures to synchronize time from time server to laptop to datalogger. The datalogger clocks tended to drift a few seconds (typically from 2 to 8) between resynchronizations. Since the timestamp in the data files is created by software that assumes a constant one-second sampling interval, there is a cumu-

lative error of 12-18 seconds over a six-hour sampling period. If these data are used for the conventional 10-minute wind averages, the aforementioned errors will be relatively small and comparisons may be made between our sites or between these data and other URBAN2000 data.

We hope to be able to release another three hours of data for some or all of the instruments. Since for the IOPs we usually initiated a new datalogging session in the evening, the additional three hours would provide data coverage through a major part of most of the IOPs. By comparing the number of data records between marker events (wind speed or direction shifts) in the data from units 300 and 500 to the other units, we can ascertain whether the sampling rate was nearly correct or whether significant undersampling was occurring. If the records correlate well, we will release more data, but since this process will be quite time-intensive we cannot estimate when this might be. If we can reliably label marker events and thereby assign real times to data that has been recorded at less than 1 Hz, we might then be able to release more data in the form of five or ten minute averages.

Table 4 provides a listing of the date and time coverage of the data files taken for each station that we are releasing at this time.

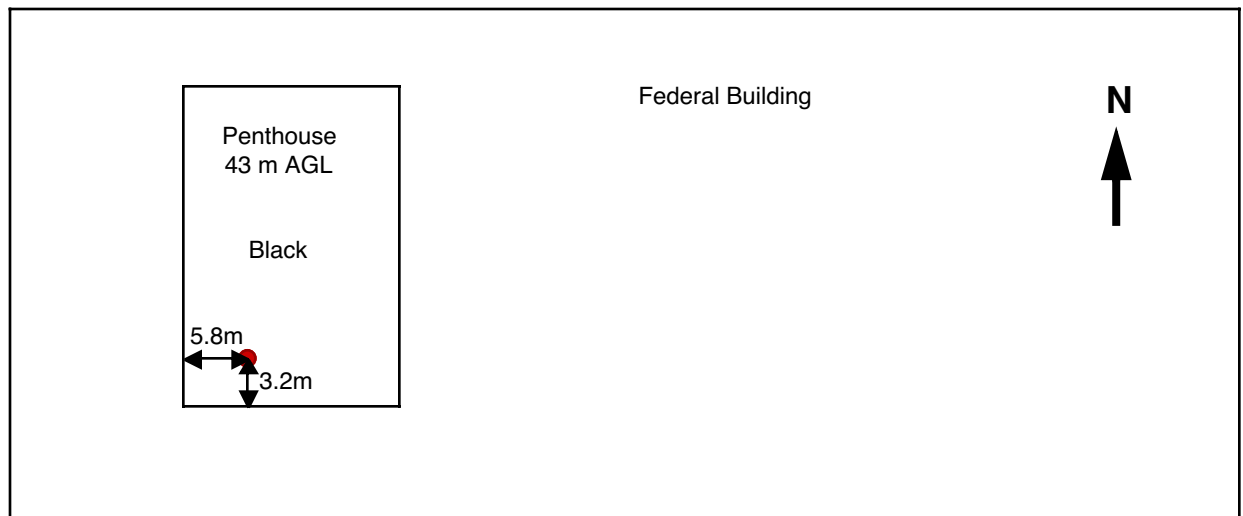


Figure 8. Rooftop Placement of Unit 200, Black.

Roof outlines of the Federal Building and the rooftop penthouse. There is no wall or barrier around the edge of the Federal Building penthouse.

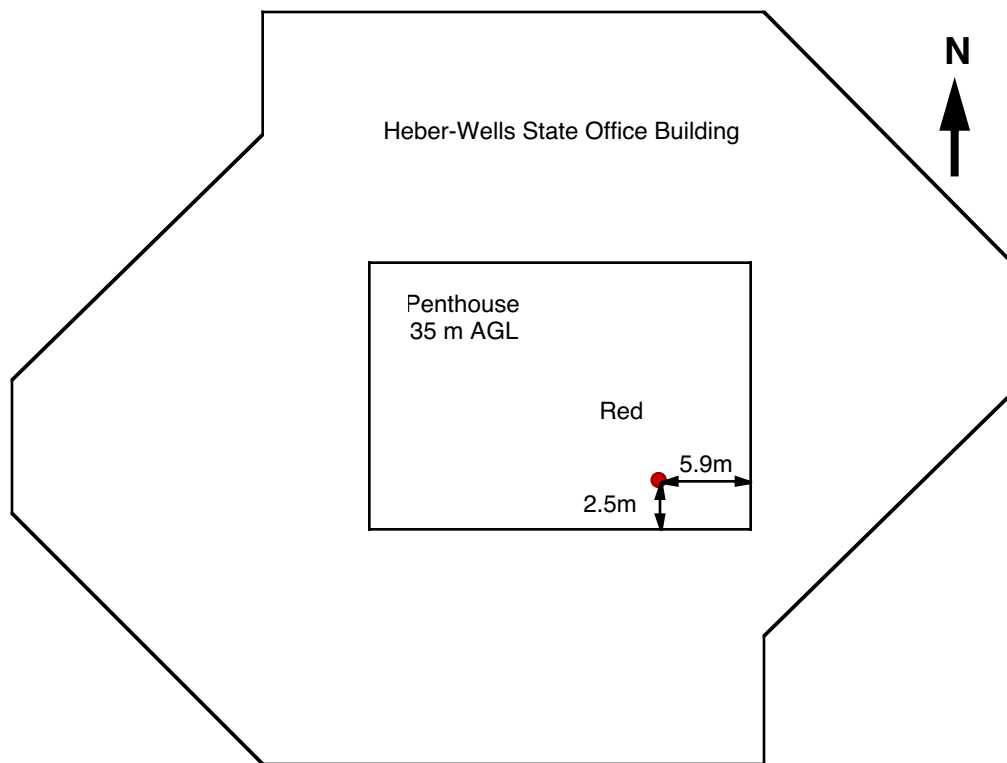


Figure 9. Rooftop Placement Unit 400, Red.

Roof outlines of the Heber-Wells Building and the rooftop penthouse. There is a low curb (20 cm high) around the edge of the Heber-Wells penthouse.

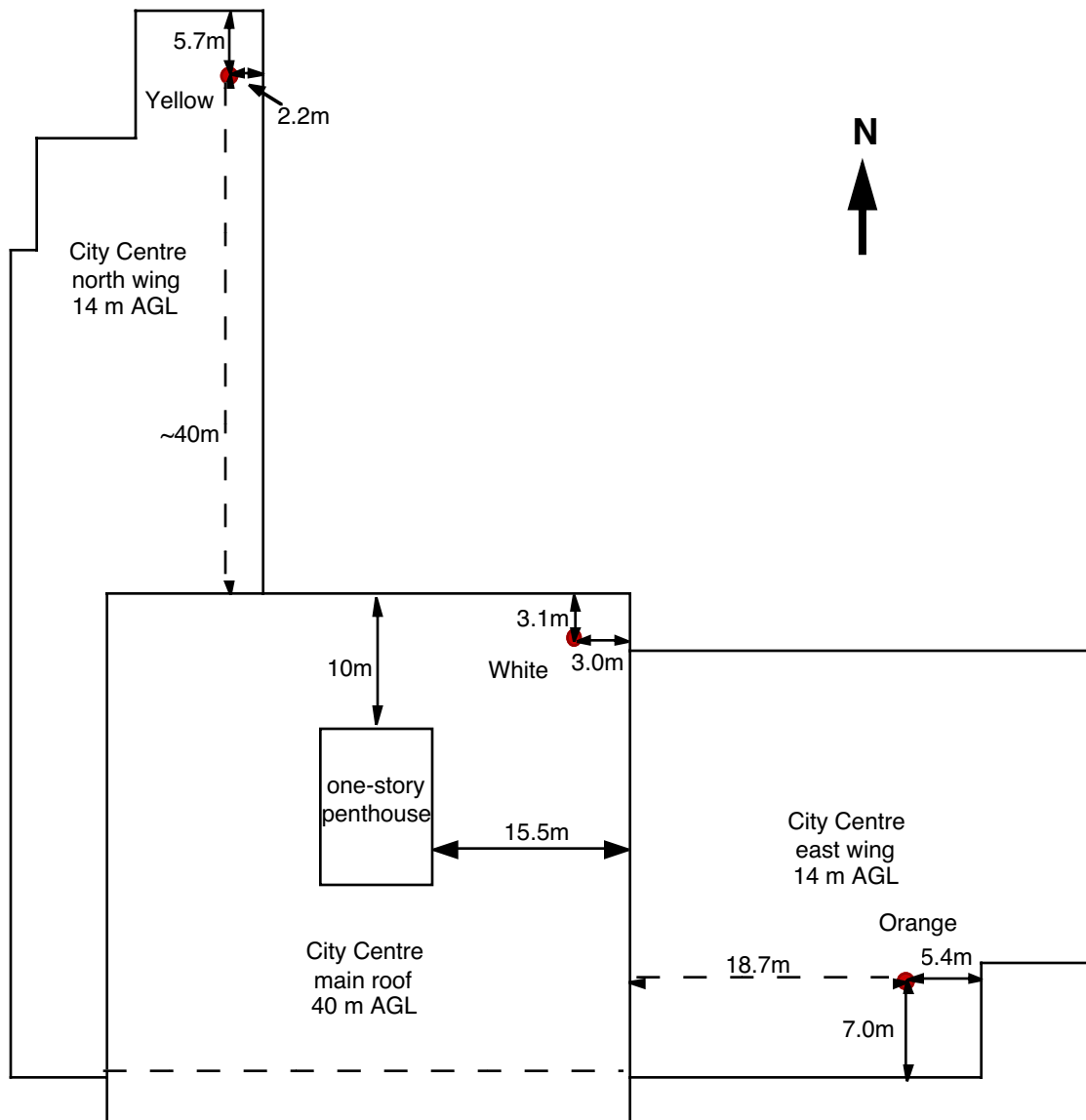


Figure 10. Rooftop Placement of Meteorological Stations on City Centre Building.

Roof outline of the City Centre Building. The upper roof is edged by a 1 m high wall. The lower roofs are edged by a 64 cm wall. A 6 cm diameter brass railing centered at 89 cm high is mounted on the low wall. Yellow is Unit 300, White is Unit 100, and Orange is Unit 600.

Table 4: Date and Time Listing of Data Files Being Released with this Report

Data files contain date and time in MDT and UTC (MDT + 6 hours), u (southerly) and v (westerly) components of the wind vector (m/s), wind speed (m/s), wind direction, and two temperature readings (upper and lower in °C) all taken at a 1 Hz sampling rate.

Whites (000)		Black (300)		Yellow (500)		Red (400)		Green (500)		Orange (600)	
Start (MDT)	Stop (MDT)	Start (MDT)	Stop (MDT)	Start (MDT)	Stop (MDT)	Start (MDT)	Stop (MDT)	Start (MDT)	Stop (MDT)	Start (MDT)	Stop (MDT)
1-Oct 11:37:41	1-Oct 17:37:40			1-Oct 11:23:02	2-Oct 03:20:00	1-Oct 10:57:01	1-Oct 18:57:00			1-Oct 11:20:44	1-Oct 17:20:43
2-Oct 11:04:05	2-Oct 17:04:04			2-Oct 10:57:03	3-Oct 10:55:00	2-Oct 10:00:02	2-Oct 18:00:01			2-Oct 11:00:02	2-Oct 17:00:01
3-Oct 12:07:63	3-Oct 18:07:61					2-Oct 20:01:03	3-Oct 02:01:02			3-Oct 02:01:03	3-Oct 08:01:02
4-Oct 03:15:42	4-Oct 09:15:41	4-Oct 10:40:68	4-Oct 16:40:65	4-Oct 03:55:00	5-Oct 07:42:61	3-Oct 11:51:05	3-Oct 17:51:04			3-Oct 12:00:65	3-Oct 18:00:64
5-Oct 00:48:08	5-Oct 06:48:05	5-Oct 10:50:00	5-Oct 16:50:03	5-Oct 00:25:04	6-Oct 03:00:02	4-Oct 03:41:37	4-Oct 09:41:36			4-Oct 03:00:57	4-Oct 09:00:56
						5-Oct 03:52:47	5-Oct 09:52:46	7-Oct 00:00:67	7-Oct 06:00:65	5-Oct 00:03:05	5-Oct 06:03:04
7-Oct 14:23:05	7-Oct 20:23:04			7-Oct 14:04:04	8-Oct 00:03:03	7-Oct 13:53:02	7-Oct 19:53:01	7-Oct 00:00:67	7-Oct 06:00:65	7-Oct 14:41:07	7-Oct 20:41:06
8-Oct 10:04:45	8-Oct 16:04:44			8-Oct 10:02:40	9-Oct 07:00:40	8-Oct 09:57:01	8-Oct 15:57:00	7-Oct 14:03:02	7-Oct 20:03:01	8-Oct 10:01:04	8-Oct 16:01:03
9-Oct 03:40:02	9-Oct 09:40:01			9-Oct 03:23:02	10-Oct 13:11:03	9-Oct 03:02:03	9-Oct 09:02:02	8-Oct 10:58:03	8-Oct 16:58:02	9-Oct 03:03:04	9-Oct 09:03:03
10-Oct 17:04:68	10-Oct 23:04:67			10-Oct 17:12:40	11-Oct 10:00:04	10-Oct 16:00:04	11-Oct 02:00:03	9-Oct 08:51:60	10-Oct 14:51:59	10-Oct 17:03:00	10-Oct 23:03:00
11-Oct 10:50:25	11-Oct 16:50:24			11-Oct 11:00:64	12-Oct 10:00:03	11-Oct 10:50:03	12-Oct 16:50:02	11-Oct 10:15:00	12-Oct 16:15:00	11-Oct 11:03:00	11-Oct 17:03:00
12-Oct 11:50:25	12-Oct 17:50:24			12-Oct 12:12:00	13-Oct 21:10:60	12-Oct 11:45:60	13-Oct 17:45:59	12-Oct 12:01:02	13-Oct 18:01:01	12-Oct 12:10:00	12-Oct 18:10:00
13-Oct 20:50:01	13-Oct 02:50:00	13-Oct 20:12:40	13-Oct 02:12:43	13-Oct 21:13:01	14-Oct 17:05:02	13-Oct 20:00:03	14-Oct 02:00:02	13-Oct 12:01:03	14-Oct 18:01:02	13-Oct 21:00:03	13-Oct 03:00:02
14-Oct 17:38:40	14-Oct 23:38:43	14-Oct 15:53:47	14-Oct 21:53:46	14-Oct 17:03:01	15-Oct 14:03:04	14-Oct 16:00:04	15-Oct 22:00:03			14-Oct 18:00:04	14-Oct 00:00:03
15-Oct 14:18:43	15-Oct 20:18:42	15-Oct 13:25:65	15-Oct 19:25:64	15-Oct 14:03:03	16-Oct 13:01:04	15-Oct 13:53:04	16-Oct 19:53:03	15-Oct 16:27:02	16-Oct 22:27:01	15-Oct 16:44:01	16-Oct 22:44:00
16-Oct 14:30:23	16-Oct 20:30:22	16-Oct 13:55:00	16-Oct 19:55:03	16-Oct 14:51:00	17-Oct 13:03:07	16-Oct 14:00:00	17-Oct 20:00:00	16-Oct 15:05:01	17-Oct 21:05:00	16-Oct 15:03:03	16-Oct 21:03:02
17-Oct 14:37:24	17-Oct 20:37:23	17-Oct 13:48:03	17-Oct 19:48:06	17-Oct 14:48:03	18-Oct 12:54:03	17-Oct 14:07:00	18-Oct 20:07:00	17-Oct 15:05:02	18-Oct 21:05:01	17-Oct 15:03:04	17-Oct 21:03:03
18-Oct 13:48:04	18-Oct 19:48:03	18-Oct 10:20:00	18-Oct 16:20:03	18-Oct 13:53:02	19-Oct 20:40:03	17-Oct 10:47:57	18-Oct 16:47:56	17-Oct 10:50:05	18-Oct 16:50:04	17-Oct 14:04:00	17-Oct 20:04:00
19-Oct 20:07:42	19-Oct 02:07:41	19-Oct 19:48:51	19-Oct 01:48:50	19-Oct 20:42:03	20-Oct 14:01:46	18-Oct 20:10:50	19-Oct 02:10:49	18-Oct 21:05:02	19-Oct 03:05:01	18-Oct 20:08:08	18-Oct 02:08:07
20-Oct 14:23:01	20-Oct 20:23:00	20-Oct 13:44:02	20-Oct 19:44:01	20-Oct 14:20:00	21-Oct 13:01:00	19-Oct 14:05:28	20-Oct 20:05:25	19-Oct 15:01:43	20-Oct 21:01:42	19-Oct 14:40:22	20-Oct 20:40:21
21-Oct 14:47:07	21-Oct 20:47:06	21-Oct 13:51:07	21-Oct 19:51:06	21-Oct 15:01:04	22-Oct 00:59:05	19-Oct 14:21:24	20-Oct 20:21:23	20-Oct 15:01:43	21-Oct 21:01:42	20-Oct 15:04:27	21-Oct 21:04:26
22-Oct 00:44:08	22-Oct 06:44:05	22-Oct 00:00:40	22-Oct 06:00:40	22-Oct 00:57:53	23-Oct 20:27:00	20-Oct 00:20:23	21-Oct 16:20:21	20-Oct 10:27:50	21-Oct 16:27:49	20-Oct 20:55:21	21-Oct 02:55:20
23-Oct 20:17:60	23-Oct 02:17:59	23-Oct 19:57:04	23-Oct 01:57:03	23-Oct 20:53:03	24-Oct 18:50:07	21-Oct 16:22:50	22-Oct 02:22:49	21-Oct 20:59:53	22-Oct 02:59:52	21-Oct 18:40:15	22-Oct 04:40:14
24-Oct 17:04:03	24-Oct 23:04:02	24-Oct 18:00:01	24-Oct 24:00:00	24-Oct 17:01:58	25-Oct 12:00:55	21-Oct 18:01:05	22-Oct 02:01:04	21-Oct 18:59:58	22-Oct 04:59:57	21-Oct 17:58:62	22-Oct 23:58:61
25-Oct 12:14:42	25-Oct 18:14:41	25-Oct 11:02:53	25-Oct 17:02:52	25-Oct 12:03:00	26-Oct 12:12:04	22-Oct 18:01:05	23-Oct 02:01:04	22-Oct 18:59:58	23-Oct 04:59:57	22-Oct 17:58:62	23-Oct 23:58:61
26-Oct 19:52:51	26-Oct 01:52:50	26-Oct 19:02:51	26-Oct 01:02:50	26-Oct 19:00:43	27-Oct 11:00:25	23-Oct 11:42:04	24-Oct 17:42:03	23-Oct 11:59:59	24-Oct 17:59:58	23-Oct 12:58:61	24-Oct 18:58:60
27-Oct 12:13:03	27-Oct 18:13:02	27-Oct 11:03:04	27-Oct 17:03:03	27-Oct 12:02:07	28-Oct 21:00:03	24-Oct 12:00:03	25-Oct 18:00:02	24-Oct 12:40:43	25-Oct 18:40:42	24-Oct 12:58:62	25-Oct 18:58:61
28-Oct 22:08:04	28-Oct 04:08:03	28-Oct 21:13:00	28-Oct 03:12:59	28-Oct 21:51:28	29-Oct 18:07:07	24-Oct 21:59:20	25-Oct 03:59:19	24-Oct 22:00:04	25-Oct 04:00:03	24-Oct 18:58:62	25-Oct 19:58:61
29-Oct 20:04:04	29-Oct 02:04:03	29-Oct 19:20:05	29-Oct 01:20:04	29-Oct 19:20:08	30-Oct 17:40:44	25-Oct 19:00:57	26-Oct 01:00:56	25-Oct 18:54:41	26-Oct 19:54:40	25-Oct 17:51:51	26-Oct 23:51:50
30-Oct 00:07:03	30-Oct 06:07:02	30-Oct 19:44:25	30-Oct 01:44:24	30-Oct 19:59:23	31-Oct 13:00:03	26-Oct 19:44:09	27-Oct 00:44:05	26-Oct 19:13:43	27-Oct 14:13:42	26-Oct 14:08:11	27-Oct 20:08:10
31-Oct 13:42:01	31-Oct 19:42:00	31-Oct 12:40:21	31-Oct 18:40:20	31-Oct 13:58:52	32-Oct 11:05:01	27-Oct 13:05:00	28-Oct 19:04:59	27-Oct 14:03:01	28-Oct 14:03:00	27-Oct 13:58:11	28-Oct 19:58:10



b) looking Northeast



d) looking Southeast



Figure 11a. City Centre East Wing Rooftop (Sensor 600, Orange). Looking a) North, b) Northeast, c) East, and d) Southeast.



Figure 11b. City Centre East Wing Rooftop (Sensor 600, Orange). Looking a) South, b) Southwest, c) West, and d) Northwest.



Figure 12a. City Centre 10th Floor Rooftop (Sensor 100, White). Looking a) North, b) Northeast, c) East, and d) Southeast.



b) looking Southwest



c) looking West (no photo)



Figure 12b. City Centre 10th Floor Rooftop (Sensor 100, White). Looking a) South, b) Southwest, c) West, and d) Northwest.



b) looking Northeast



d) looking Southeast



Figure 13a. City Centre North Wing Rooftop (Sensor 300, Yellow). Looking a) North, b) Northeast, c) East, and d) Southeast.



b) looking Southwest



c) looking West



d) looking Northwest

Figure 13b. City Centre North Wing Rooftop (Sensor 300, Yellow). Looking a) South, b) Southwest, c) West, and d) Northwest.



Figure 14a. City Centre Parking Lot (Sensor 500, Green). Looking a) North, b) Northeast, c) East, and d) Southeast.



b) looking Southwest



d) looking Northwest



Figure 14b. City Centre Parking Lot (Sensor 500, Green). Looking a) South, b) Southwest, c) West, and d) Northwest.



Figure 15a. Heber Wells Rooftop (Sensor 400, Red). Looking a) North, b) Northeast, c) East, and d) Southeast.



Figure 15b. Heber Wells Rooftop (Sensor 400, Red). Looking a) South, b) Southwest, c) West, and d) Northwest.



Figure 16a. Federal Building Rooftop (Sensor 200, Black). Looking a) North, b) Northeast, c) East, and d) Southeast.



a) looking South



b) looking Southwest



c) looking West



d) looking Northwest

Figure 16b. Federal Building Rooftop (Sensor 200, Black). Looking a) South, b) Southwest, c) West, and d) Northwest.

Urban Heat Island (UHI) Measurements and Analysis

Spatially-resolved temperature measurements were made during several nights from a moving van in and around Salt Lake City and the nearby rural areas. The measurements occurred during one week of the DOE CBNP URBAN2000 Field Experiment conducted in October 2000.

A factory-calibrated, high-precision thermistor temperature probe and GPS were affixed to the outside of a cargo van (Figure 17) and used to record temperature and position directly to two PC laptops. The instrumented van was driven over three primary routes, two including downtown, residential, and “rural” areas and a third that went by a line of permanently fixed temperature probes for cross-checking purposes. Figures 18 and 19 show examples of temperature measurements over a data track; the former as a function of location and the latter as a function of time. Each route took from 45 to 60 minutes to complete. Four nights of measurements are presented in the UHI data report for the period Oct. 22-26, 2000.

The measurements reported therein are intended to supplement the meteorological measurements taken during the URBAN2000 Field Experiment. The temperature measurements will be useful for assessing the importance of the urban heat island phenomenon in Salt Lake City and for testing the urban canopy parameterizations that have been developed for regional scale meteorological codes as part of the DOE CBNP program. Initial analyses indicate that there is a temperature difference of from 2-5 °C between the urban core and nearby “rural” areas. Analyses also suggest that there are significant fine scale temperature differences over distances of tens of meters within the city and in the nearby rural areas. See Brown and Pardyjak (2001), footnote 1 on page 17, for more information.



Figure 17. Van, showing location of GPS unit and thermistor probe, used for urban heat island measurements.

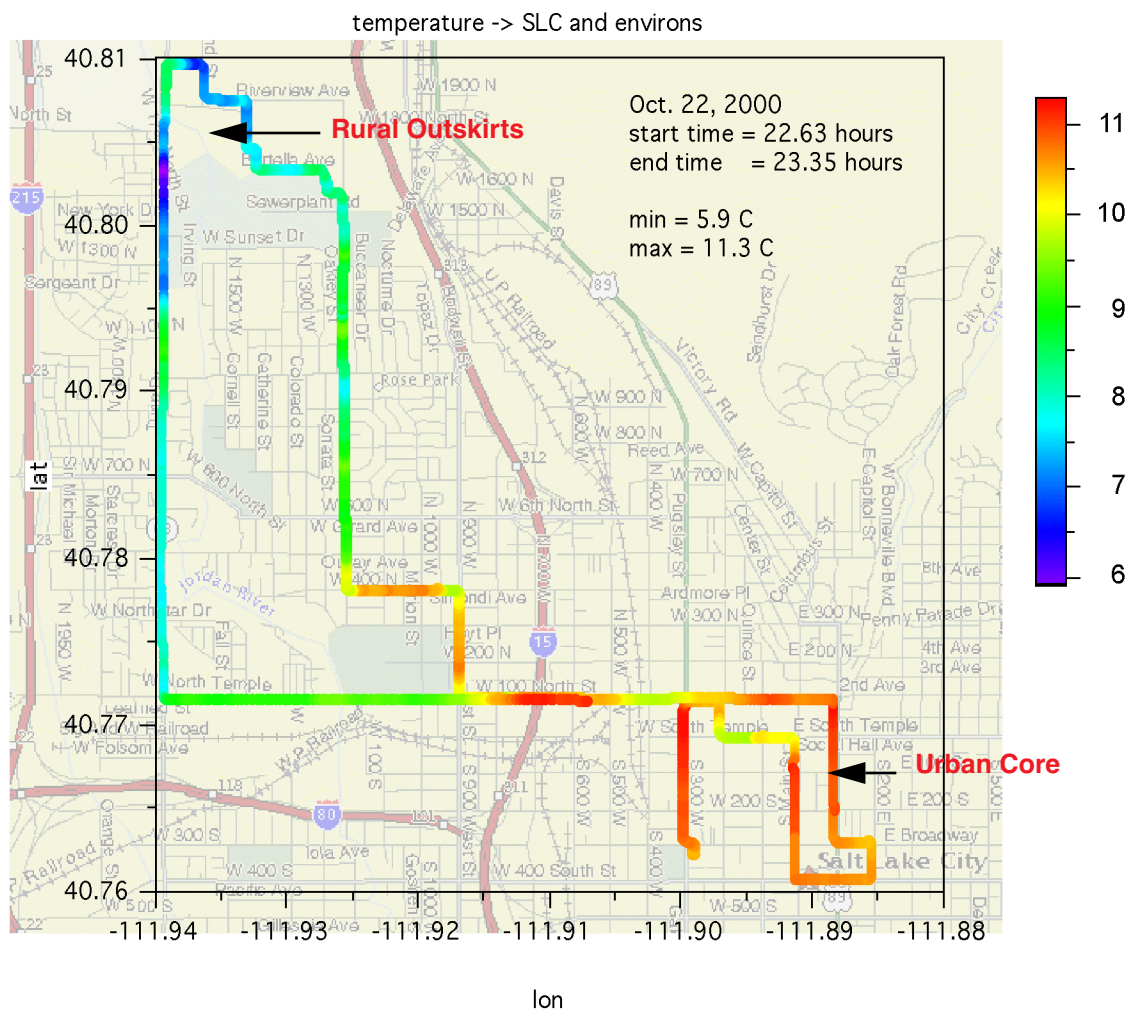
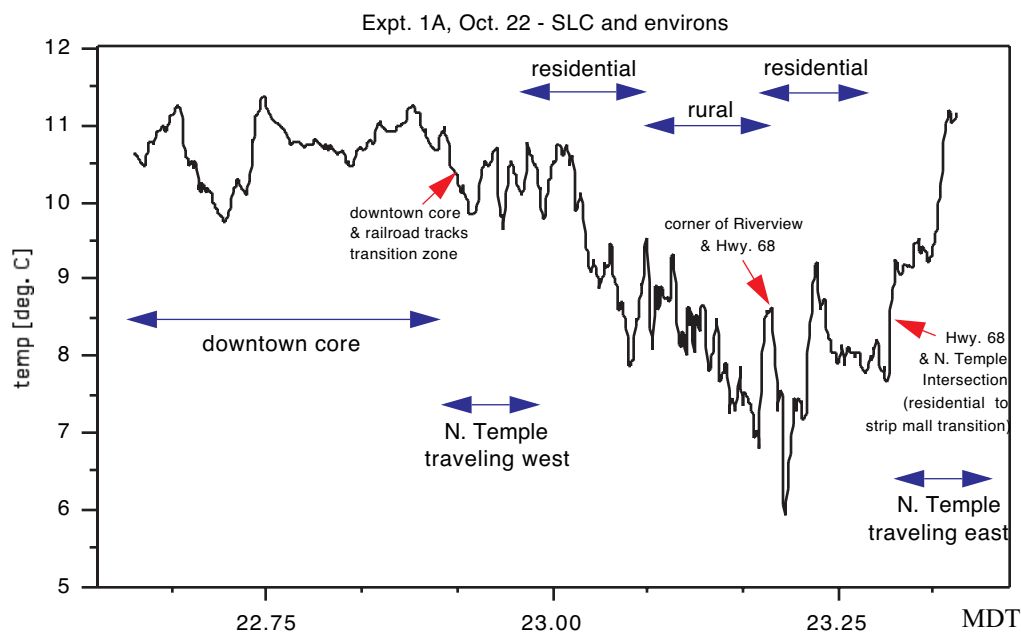


Figure 18. An example track and data display from the UHI measurements showing warmer temperatures in the urban core and cooler temperatures in the rural outskirts.

Figure 19. Temperature vs. time while driving a route.



Sky View Factors and Analysis

As part of the October 2000 URBAN2000 Field Experiment in Salt Lake City, upward pointing fisheye photographs were taken in the downtown area from ground level in order to compute the sky view factor (Ψ_{sky}). Using image analysis and in-house processing software¹, Ψ_{sky} was computed for each photograph. This section provides a brief overview of what the sky view factor is, why it is important in meteorological studies of urban areas, and how it is computed from fish-eye photographs. The range of Ψ_{sky} observed in Salt Lake City was from 0.33 to 0.90, with an average of 0.70 based on 93 images taken in the downtown area.

-
1. Grimmond, C.S.B., S.K. Potter, H.N. Zutter, and C. Souch (2001) Rapid methods to estimate sky view factors applied to urban areas, Int. Journ. Climatology. (in press).



Figure 20. A fisheye view in Salt Lake City from which sky view factors are computed.

The ratio of the radiation received (or emitted) by a planar surface to the radiation emitted (or received) by the entire hemispheric environment is called the sky view factor Ψ_{sky} ¹. Sky view factor is used in radiation balance schemes to partition long and shortwave radiation within urban and forest canopies and complex terrain. In the urban environment, Ψ_{sky} and $1-\Psi_{\text{sky}}$ give a measure of how much radiation will penetrate the canopy and how much will be intercepted by the canopy, respectively.

1. Watson, I. and G. Johnson (1987) Graphical estimation of sky view-factors in urban environments, Journ. Climatology, 7, 193-197.

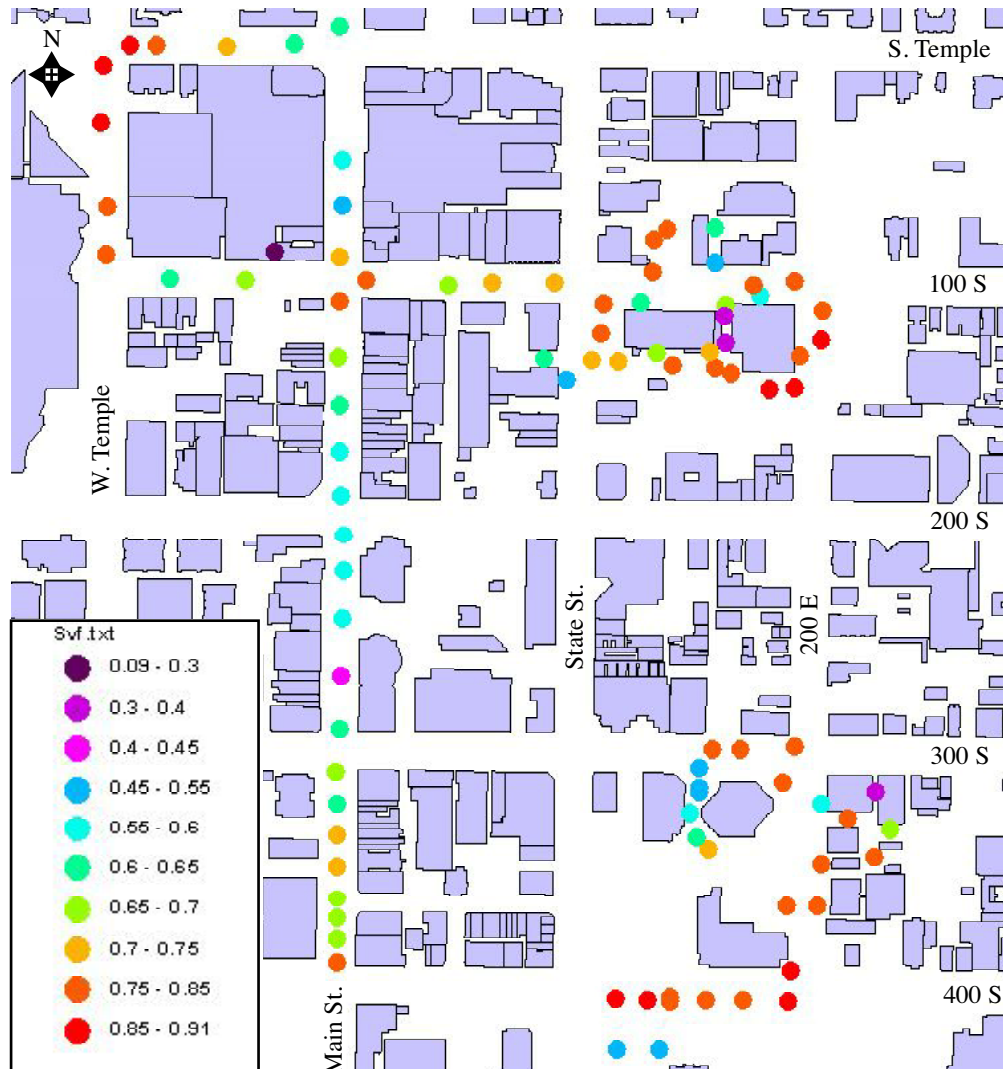


Figure 21. The computed sky view factor overlaid onto downtown Salt Lake City building footprint map. Photos taken Oct. 22, 2000.

In the Salt Lake City study, a digital camera (Nikon CoolPix 950) with a fisheye hemispheric lens (Nikon FC-E8) was used to take the *in situ* observations. Figure 20 provides an example. The Nikon lens used has a field of view (FOV) of 189° (Grimmond et al. 2001). The images are converted from color to black (ground, buildings, and vegetation) and white (sky) by altering the brightness and contrast of each image using Paint Shop Pro (Jasc Software). The black and white images are saved in portable greymap (jpg) format. To determine the total Ψ_{sky} at each site the equation of Johnson and Watson¹ is used:

$$\varphi_{sky} = \frac{1}{2\pi} \sin \frac{\pi}{2n} \sum_{i=1}^n \sin \left[\frac{\pi(2i-1)}{2n} \right] \alpha_i$$

where n is the total number of annuli, i is the annulus number and α_i is the total angular extent of sky visible in each annulus. This is done using the Grimmond et al. (2001) purpose written Fortran program (svf.exe). This program automatically detects the resolution of the image taken, and allows the user to specify the FOV to be analyzed; i.e. corrections to 180° were included at this stage. Figure 21 depicts locations in which sky view photos were taken and the computed sky view factor at each point.

1. Johnson, G.T. and I.D. Watson (1984) The determination of view factors in urban canyons, Journ. Clim. and Appl. Meteor., 2, 329-335.

V Instruments and Instrument Calibration

The primary instruments used by LANL researchers in the URBAN2000 field campaign were HANDAR 425A Ultrasonic Wind Sensors operated at 1 Hz. From the HANDAR catalog, “The 425 boasts a confirmed operating range of 0 to 144 m.p.h. (0 to 65 m/s or 0 to 125 kts), thus capable of withstanding strong, hurricane-force winds. Wind speed accuracy is ± 0.3 m.p.h. (0.135 m/s or 0.26 kts), or $\pm 3\%$ of the reading (whichever is greater) for wind speed measurements up to 110 m.p.h. (49.5 m/s or 95.5 kts), and $\pm 5\%$ of reading for measurements of 110 m.p.h. or greater. Wind direction accuracy is within ± 2 degrees. Wind direction resolution is 1 degree, while wind speed resolution is 0.1 m.p.h. (0.045 m/s or 0.87 kts). The 425A draws little power (12 V D.C. source), ideal for remote solar-powered systems. The 425A has an operating temperature range from -40 to +50C.”

Each station had a HANDAR 555C Data Acquisition System (DAS) with the optional Expanded Memory Module so data could be written to a PCMCIA SRAM card. The specifications of the DAS follow (from the Vaisala Handar Business Unit Product Catalog).

Inputs

16 user-configurable analog: single-ended or 8 paired differential with on board patch locations for resistive pull-up/pull-down and differential shunt

Resolution: 14-bit ADC

Range and Accuracy:

-2.5 to 5 V.025% RMSE (temperature compensated)

-25 to 50 mV.05% RMSE (temperature compensated)

1 frequency input: 0-3,000 hz (wind speed)

1 programmable counter input: 16-bit count to event trigger

1 switch closure input (tipping bucket)

1 SDI-12 Smart Sensor Interface

8 programmable digital inputs: event on \pm or both input transitions

Outputs

8 programmable digital outputs

2 independent switched 12 V outputs: 750 mA maximum each

1 precision +5 V output: 20 mA max.

1 program I/O port: interfaces to MS-DOS compatible PC for programming and/or data retrieval

Memory Storage: 128 Kbytes of RAM

Real Time Clock: 15 second/month maximum drift, temperature compensated, 30 sec./year max. drift (GOES option)

Temperature Range: -40 to 55 degrees C standard; -55 to 85 degrees C extended.

Enclosure: NEMA - 4

Connection Types: Program I/O: 9-pin CPC type, Sensor Interface: 3 37-pin CPC

Power: 12 V battery, Solar Panel

Weight: 9 lbs (4.08 kg) with battery

The data logging process is programmable through PC compatible software. A customized data logging program (in our case wind speed, wind direction, u and v wind components, and two thermistor readings, all at 1Hz) is compiled on the PC and uploaded to the DAS. The 2 MB PCM-CIA SRAM cards that we used gave us logging capability for well over 24 hours.

The thermistors used at our stations were Omega “400” Series, specifically model 405 Air Temperature Probes. These are 2252 ohm (at 25 °C) probes with a sensor accuracy of ± 0.1 °C and a 10 second time constant. The time constant represents the time to reach 63% of a sudden change in a well-stirred water bath. Five time constants are required to reach 99% of the total change. The time constant in air is about 100 seconds. Since air temperature changes are small over the time scale of minutes we recommend that a two minute or longer averaging period be used when analyzing the thermistor measurements.

The precision thermometer (thermistor-based) used to calibrate the Omega thermistors and for the urban heat island measurements was a YSI 4600S (Transfer Standard). The YSI 4600S offers metrology-level accuracy over user-defined temperature ranges. Our unit was calibrated at five points with a YSI 052 Bird Cage Air Probe and has certified NIST traceability. The calibration readings are as follows, all in stirred oil baths. The time constant, in oil, was specified to be 1.0 second.

<u>Temperature</u>	<u>4600S Reading</u>
-40.000°C	-39.993
0.000°C	0.005
40.000°C	39.990
70.000°C	69.992
25.000°C	24.997

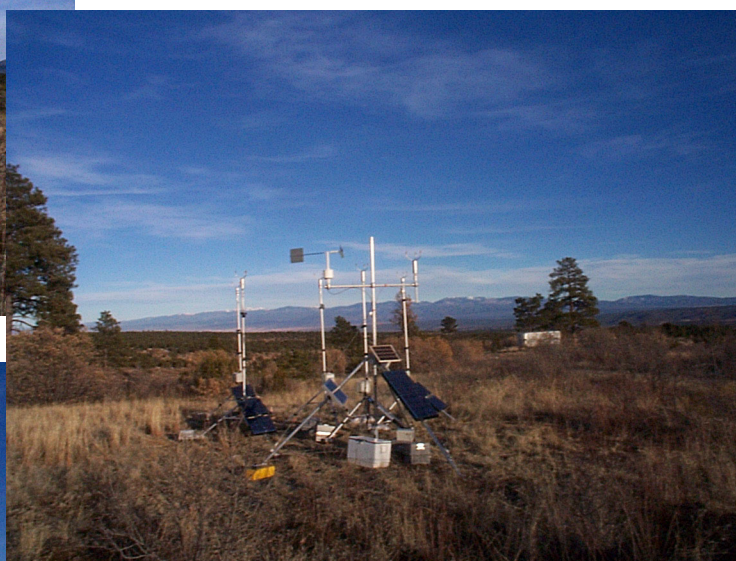
Sonic Anemometer Calibration

A post-experiment calibration was performed on the sonic anemometers during mid to late November 2000. The calibration procedure consisted of cross-correlating the six different Handar ultrasonic anemometers and a calibrated prop-vane anemometer. The units were placed on a mesa in a field located at LANL’s TA-49 meteorological measuring station. Figure 22 displays photographs of the site and calibration setup. Figure 23 is a to-scale schematic showing the orientation of the measuring instruments with respect to the TA-49, 32-meter tower. The area was relatively flat and mostly free from obstructions. One medium Juniper tree is nearby and is noted in the figure.



a.

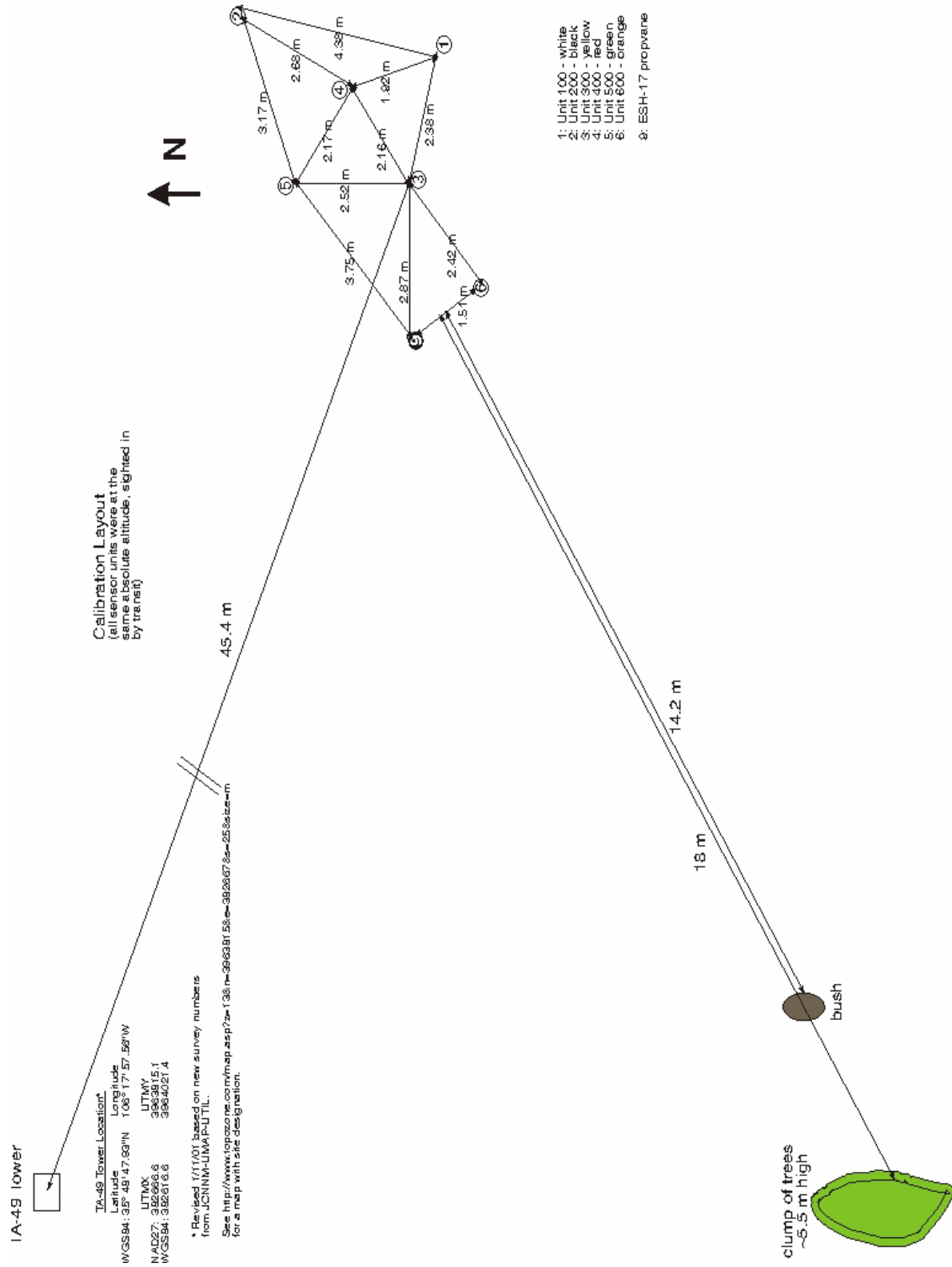
b.



c.

*Figure 22. Photos of the calibration layout.
a) looking NW past the TA-49 tower; b) looking
NE, c) looking E.*

Figure 23. Scaled schematic of instrument location and spacing for calibration measurements.



The weather conditions during the November calibration period could be characterized as fairly calm and dominated by local thermally-driven winds. During the day the winds were typically from the east/southeast and during the night from the west/northwest. This is the typical anabatic/katabatic flow pattern in the area. A winter storm did move in on November 23, but this data was not included in the calibration procedure.

As can be seen in the photos an RM Young prop-vane was used in the calibration layout. This was a model 35005 with a polystyrene propeller, for low threshold, and a quoted accuracy of ± 0.2 m/s and $\pm 3^\circ$. The startup threshold is 0.1 to 0.2 m/s.

In an effort to quantitatively compare the various wind sensors, two bias statistics were used. The first, η , was a relative bias and the second, γ , was an absolute bias. The following are the equations for the two statistics used:

$$\eta = \frac{\sum_1^N \frac{|x - y|}{\frac{1}{2}(x + y)}}{N}, \text{ and}$$

$$\gamma = \frac{\sum_1^N |x - y|}{N},$$

where x is the data for one sensor, y is the data for any other sensor, and N is the total number of data points. The bias statistics measure the average distance of data pairs from a perfect 1:1 correlation, but do not give the direction of the bias. The relative bias statistic is normalized to remove the influence of the arbitrary, actual values of the data (i.e., relatively small numbers for wind speed and typically much larger numbers for wind direction).

Scatter plots for the wind speed and wind direction cross-correlation comparison of the six Handar ultrasonic anemometers with each other and with the prop-vane anemometer may be found in Appendix A. The plots include the calculated bias statistics. Also included are some sample time series data plots for sonic data, prop-vane data and TA-49 met tower. The first set of data shown was taken during on November 16, 2000 from approximately 1335LST to 2359LST. The second set of data was taken during the day on November 21, 2000 from approximately 1100LST to 1700LST. All data were sampled at 1 Hz and then resolved into components and vector averaged into five minute samples before the wind speed and wind direction were calculated. Each of the scatter plots contains a “one-to-one” line corresponding to a perfect correlation. The wind

speed plots are color coded with wind direction to identify possible physical mechanisms for discrepancies in wind speed, while the wind direction plots are color coded with wind speed.

The sensors were deployed at the calibration site for about a week and a half and substantially more data was recorded than just on those two dates mentioned in the preceeding paragraph. However, working with some of the data from long recording sessions yielded a second “discovery” of the data recording problem that we were just then discovering in the Salt Lake City data. Hence, we used data from two of the shorter recording sessions for the calibration study. While the November 16 session was about ten hours in length, only the black, yellow, red, and orange sensors were operated. In our in-depth timing and recording study these sensors all showed good behavior out to nine hours. The black and red units typically lose about two minutes of data in the tenth hour and this would not severely affect the calibration study. The November 21 session was only about six hours long so there would be no data recording problems.

The wind speed correlations on 16Nov seem to be somewhat poorer than those on 21Nov. Part of this may be explained by the fact that there are more very low wind speeds (<0.5 m/s) in the 16Nov data. Both data sets show poorer correlations for winds coming from about 200° . This is the general direction of the clump of trees. In the wind direction correlations for 16Nov it is obvious that low wind speeds, but not all low wind speeds, contribute to the scatter. The wind speed correlations for 21Nov are very good.

Prior to deployment in Salt Lake City three of the anemometers (white 100, black 200, and red 400) were sent back to Handar for alignment, transducer replacement and calibration. The Handar calibration procedure involves placing the units into a wind tunnel, aligning them, and checking to make sure the speeds and direction are within the published specifications. Based on the factory calibration of the three units and the good cross-correlation of the units with each other, along with the lower stated accuracy of the prop-vane unit, it was determined not to make any calibration adjustments to the wind speed and wind direction data for the URBAN2000 experiment.

Thermistor Calibration

This section contains the calibration data for 11 of the 12 Omega ON-405-PP thermistors (interchangeable accuracy of $\pm 0.1^\circ\text{C}$) used during the URBAN2000 field campaign. This data was also taken post-experiment in November 2000. The lead to the lower thermistor on the green unit was cut sometime during the sonic anemometer calibration procedure so this thermistor was not functioning during the subsequent thermistor calibration procedure. Data logging during calibration was done as described earlier for the field experiment, but for much shorter time periods so

the data recording problem at long time was not an issue. Calibration was done in a water bath at multiple temperatures and in an air stream, nominally at fixed temperature, but at four different wind velocities.

An attempt to calibrate in air within an insulated box was quickly abandoned. Though the air was stirred with a small electric fan we could not be certain of temperature uniformity in the box. The possibility of thermistor self-heating and a noticeable hysteresis when switching from cooling to heating or vice-versa made this procedure very problematic.

To address the issues just raised in the initial calibration attempt, a two-part calibration study was adopted. The first part was a water bath temperature calibration. A water bath ensures that the thermal conductivity is sufficiently high that self-heating would not be an issue and the time constants would be short. The second part was an air calibration utilizing a box fan to vary the wind speed over the thermistors. This was to test if, and how much, the temperature correction varied as a function of wind speed (or effective thermal conductivity). In particular, it is desirable to know if there is a minimum wind speed under which the calibration data would be inappropriate to apply to the field data.

Water Bath Calibration Procedure

The water bath calibration procedure consisted of taking nine data points, as uniformly spaced as possible, in the temperature range found during the field experiment (0-25 °C) and then comparing them to the YSI 4600 Precision thermistor (accuracy ± 0.025 °C). The probes were kept in close proximity to one another (within 6 cm or less), submerged well below the surface and kept away from the walls of the container. The zero point of the YSI standard probe was checked with a non-distilled ice water bath and was measured as 0.01 °C. The water bath was stirred before each temperature measurement after the temperature was increased. The data at each temperature point were averaged for a minimum of two minutes during which the change in the bath temperature was an order of magnitude smaller than the YSI rated accuracy. Calibration factors were calculated from a linear least squares fit between the YSI standard and each thermistor. Since the Chi-squared value of each of the sensors was unity (to within the accuracy of the instruments), only a fixed (intercept) offset was applied to each sensor. Calibration data plots may be seen in Appendix B, pages B-3 through B-6.

Sensor1 is the higher-mounted of the two thermistors and corresponds to temp2 in our processed data files. Sensor2 is the lower-mounted of the two thermistors and corresponds to temp1 in our processed data files. All of the Omega thermistors read high compared to the YSI standard so these offsets have been subtracted from the raw data in producing the processed data files.

Because eight of the eleven thermistors had a 0.3° offset, that offset was chosen for and applied to Green sensor2 that we were not able to calibrate. The temperature offsets, rounded to 0.1 deg, are:

Unit 100-white:	Sensor1: 0.3 deg, Sensor2: 0.3 deg
Unit 200-black:	Sensor1: 0.3 deg, Sensor2: 0.3 deg
Unit 300-yellow:	Sensor1: 0.3 deg, Sensor2: 0.4 deg
Unit 400-red:	Sensor1: 0.3 deg, Sensor2: 0.2 deg
Unit 500-green:	Sensor1: 0.2 deg
Unit 600-orange:	Sensor1: 0.3 deg, Sensor2: 0.3 deg

Air Calibration Procedure

The air calibration procedure involved placing a 2-D Handar ultrasonic anemometer approximately 60 cm from a standard 3-speed, 1 m x 1 m, household box fan. The YSI standard probe and the Omega thermistors were placed at the end of a rod and located approximately at the center of the measuring volume of the sonic anemometer. Data was taken with the fan off (0 m/s) and at three fan on settings that provided winds at about 2.5, 3.3 and 4 m/s. Thermistor data was taken for 30 minutes at each wind velocity. Temperature measurements at all wind speeds fell within the stated accuracy of the thermistors. Calibration data plots may be seen in Appendix B, pages B-7 through B-9.

Conclusions

The water bath study provided very high-quality data for determining temperature offsets for the Omega thermistors. These values were used for calibrating the URBAN2000 data. In the wind speed study all of the sensors showed similar behavior with the deviation from the standard increasing slightly at low wind speed, or under poor thermal conductivity conditions. However, after the correction factors derived from the water bath test are applied the deviations are within or very close to the $\pm 0.1^{\circ}\text{C}$ interchangeable accuracy specified by Omega. We do not believe that we have adequate data or adequate justification to attempt to make wind speed specific corrections so only the offsets as determined from the water bath measurements have been applied.

Due to the in-air time constants of the Omega thermistors we recommend that the temperature data from URBAN2000 be used in no less than two-minute averaging periods.

VI Samples of Data and Analyses

Table 4 in section IV lists the data files that are now available from the wind and temperature stations deployed during the month of October by Los Alamos researchers. Further information on the urban heat island measurements and the sky view factor measurements is available in the reports cited in section IV.

By our definition raw data is data as downloaded from the dataloggers. Processed data has had calibration corrections applied and no-value points removed. No-value points, if any, would be recorded for one of the sensors at the very beginning of a data file. As discussed in section V, calibrations were applied only to the temperature data. All discussion and examples given in this section refer to processed data. All data files are constructed as shown in the example below. This example is for unit 300 (yellow) on Oct. 2. The header contains unit identification, location, roof height above ground, sensor heights above the roof, and the start and stop times for the data in the file. The header, including a blank line, is always seven lines. The columnar data provides date and time in MDT and UTC, incremental time for this file in seconds, u and v wind vector components, resultant wind speed and direction, and two temperature readings. All the data is at one second frequency.

The header has no commas so it will not influence column structure if the file is read into a spreadsheet. The columnar data is comma delimited. For those applications, such as Microsoft Excel, that can parse a date-time expression in one column, simply do a search in a text editor for “-00,” and delete the comma.

```
Data courtesy of Los Alamos National Laboratory reference LA-UR-01-950
Sensor 300(yellow) City Centre NW utmx=425180 utmy=4512665 (NAD83)
Roof ht: 13.61m anemometer ht: 3.46m templ ht: 0.59m temp2 ht: 2.0m
Data processed and calibrated +u=west wind(from the west)
'+v=south wind(from the south) 0/360 deg=north wind 90 deg=east wind
File start: 02-Oct-00 10:57:18 (MDT) File end: 03-Oct-00 10:35:30 (MDT)
```

Date,	Time(MDT),	Date,	Time(UTC),	t(s),	u(m/s),	v(m/s),	ws(m/s),	wd(deg),	templ(C),	temp2(C)
02-Oct-00,	10:57:18,	02-Oct-00,	16:57:18,	0,	-0.3,	0.1,	0.4,	104,	25.9,	25.7
02-Oct-00,	10:57:19,	02-Oct-00,	16:57:19,	1,	-0.7,	-0.1,	0.7,	82,	26.0,	25.8
02-Oct-00,	10:57:20,	02-Oct-00,	16:57:20,	2,	-0.5,	-0.1,	0.5,	81,	26.0,	25.8
02-Oct-00,	10:57:21,	02-Oct-00,	16:57:21,	3,	-0.5,	-0.3,	0.6,	60,	26.0,	25.8
02-Oct-00,	10:57:22,	02-Oct-00,	16:57:22,	4,	-0.4,	-0.3,	0.5,	51,	26.1,	25.8
02-Oct-00,	10:57:23,	02-Oct-00,	16:57:23,	5,	-0.2,	-0.2,	0.3,	49,	26.1,	25.8
02-Oct-00,	10:57:24,	02-Oct-00,	16:57:24,	6,	-0.2,	-0.2,	0.3,	49,	26.1,	25.8

Our currently released dataset is graphically displayed in Appendix C. Page C-3 is a reprise of Table 4, but with Appendix C page numbers added to help locate a desired plot. The graphs are 24 hour displays for a day in UTC, that is 00-24 UTC. MDT equals UTC - 6 hours so in MDT this

time period is from 1800 (6 pm) on one day to 1800 (6 pm) on the next day. This display format was chosen so that each IOP would be fully contained within one graph.

Time averaging is a simple data processing technique. Figure 24 a, b, and c shows ten minute averaged data from the green sensor (unit 500) for the period of IOP10. The wind speed and wind direction are based on vector averaging. Figure 25 shows a visual representation of wind vectors, again a ten-minute average, during the IOP10 tracer release. Shown are four LANL sensors and six sensors deployed by LLNL during the IOP. LANL unit 500 (Orange) was not operating during this IOP. It is evident that winds are very light at this time.

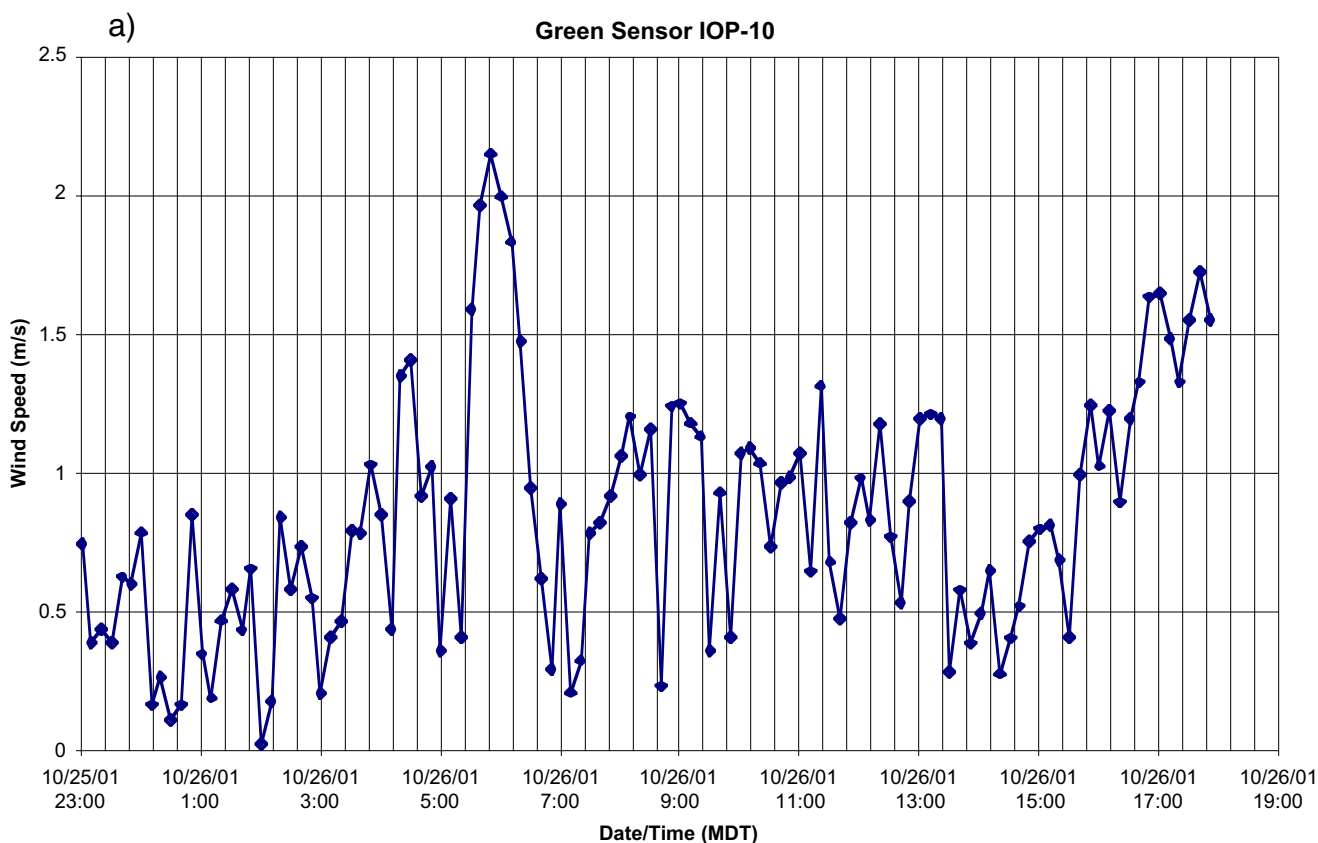
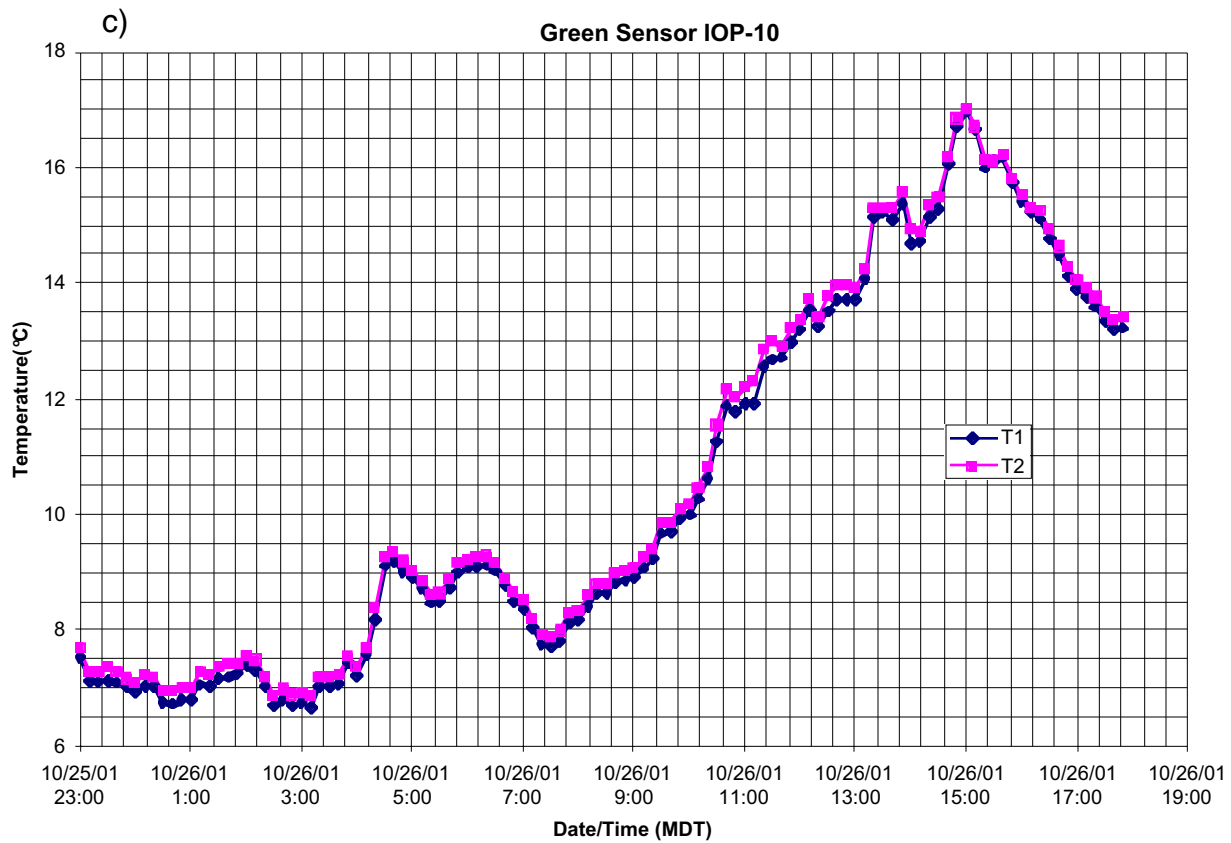
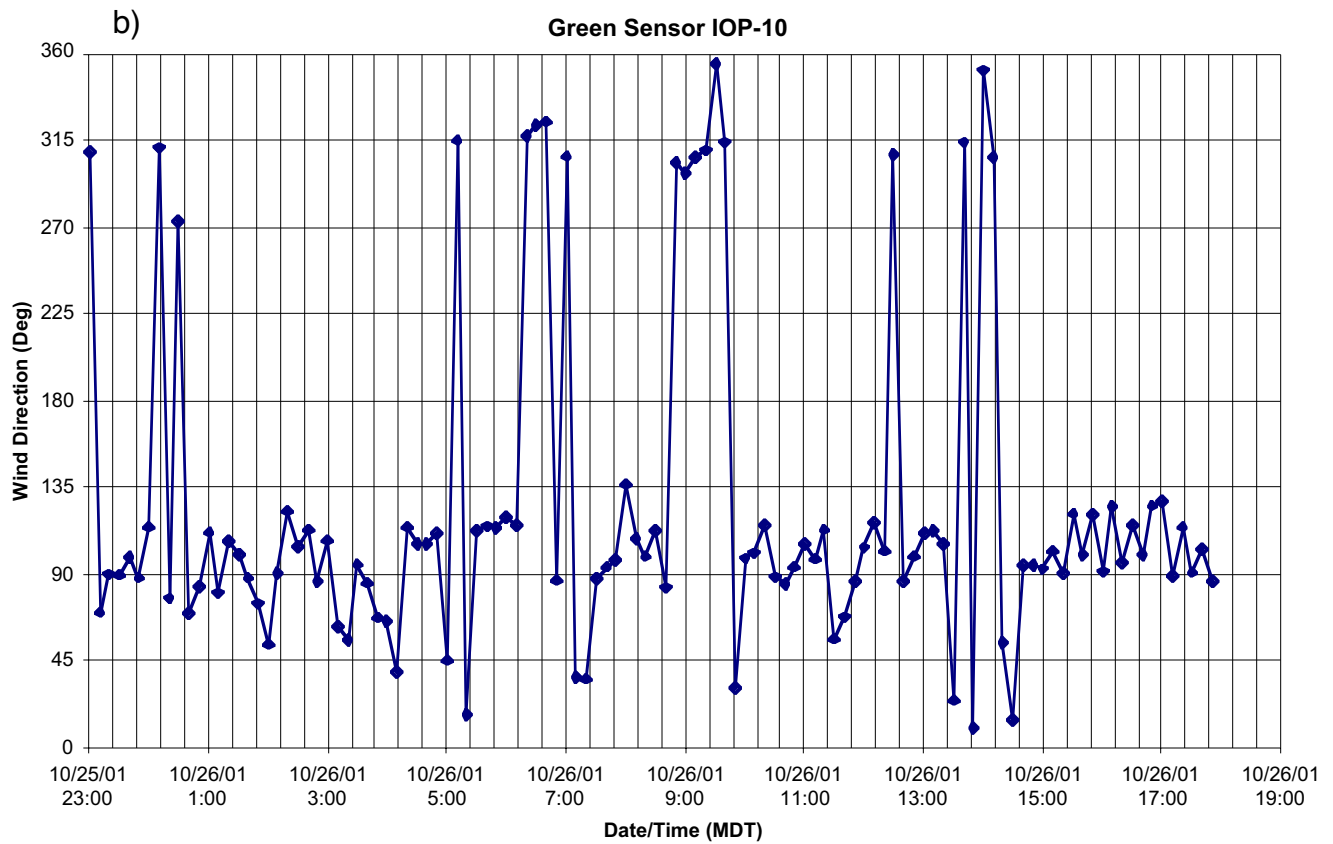


Figure 24a (above). Ten-minute vector-averaged wind speeds from the green sensor (unit 500) during IOP10. Figure 24b and c (next page). Ten-minute vector-averaged wind direction and ten-minute averaged temperatures from the green sensor during IOP10. This sensor was mounted on a lightpole in the parking lot between the City Centre and Heber-Wells buildings.



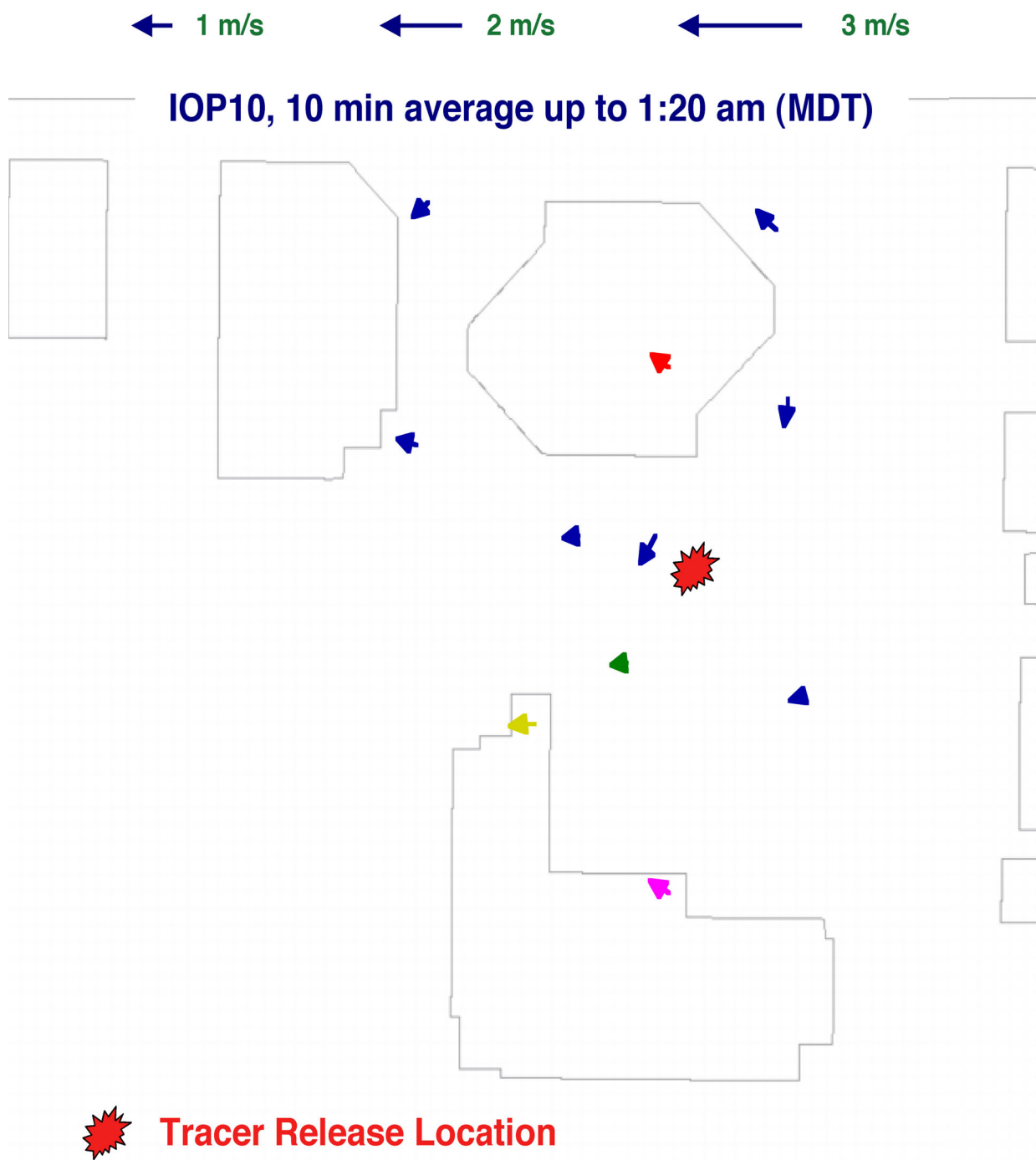


Figure 25. Representation of ten-minute averaged wind vectors during the first tracer release period of IOP10. The red, green, and yellow vectors represent the LANL instruments as designated by those colors (Units 400, 500, and 300 respectively). The pink vector is the LANL white (Unit 100) instrument. The blue vectors are the LLNL instruments deployed during the IOP. At this time, all of the averages are well under 1 meter/second.

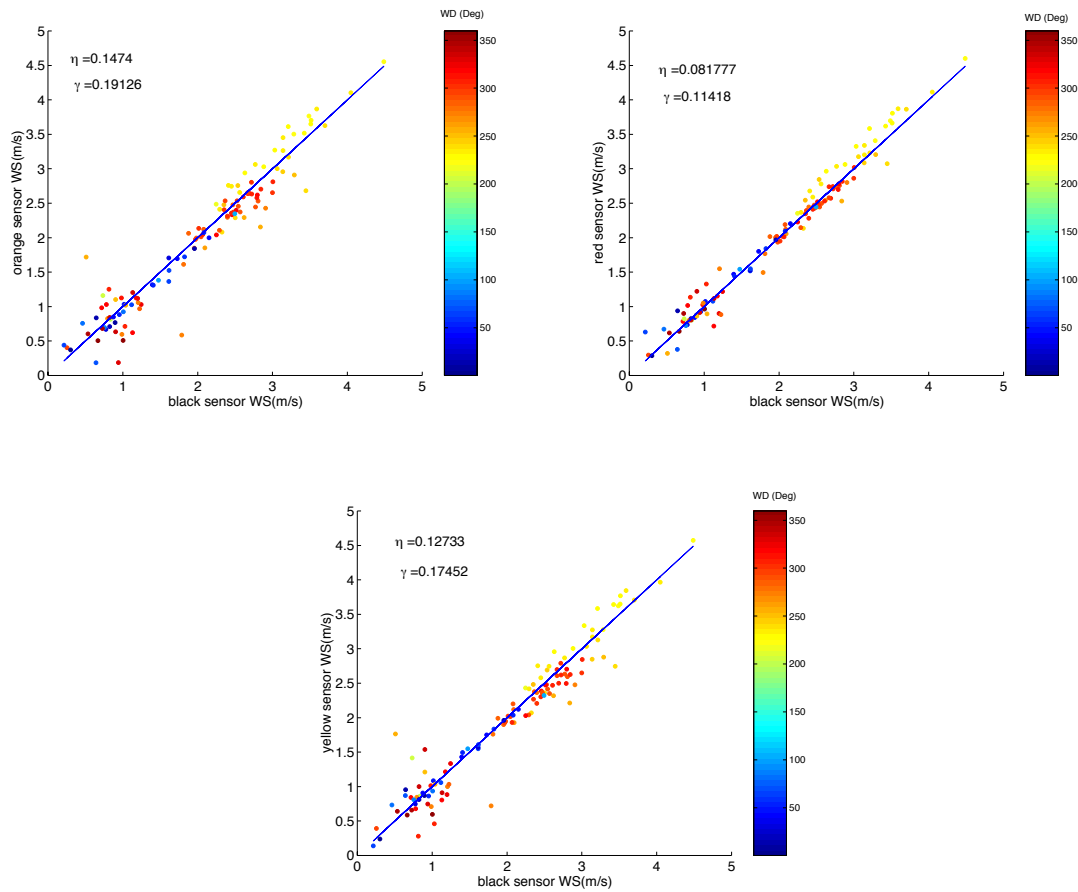
**The DOE CBNP Salt Lake City
URBAN Experiment of October 2000**

**LANL Urban Wind and Temperature
Measurements Data Report**

Appendix A: Ultrasonic Anemometer Calibration Data Plots

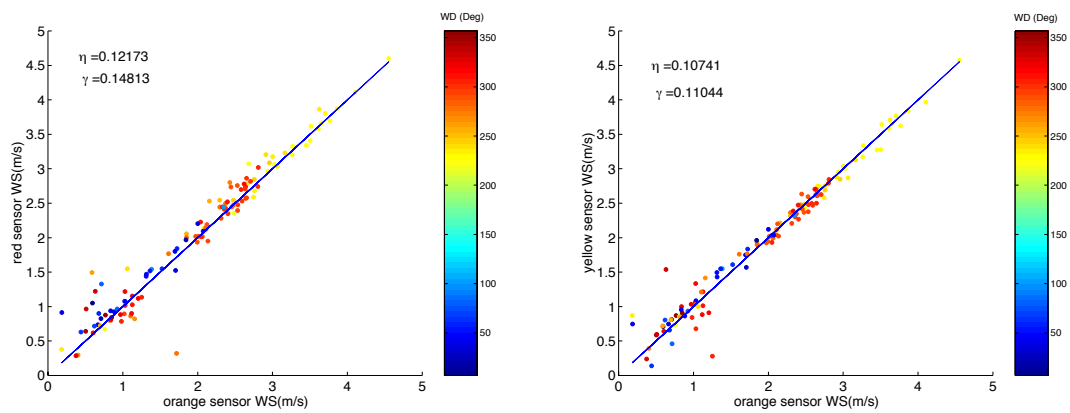
Wind Speed Comparison 11/16/2000 (afternoon and night)

Black Sensor Cross Correlation

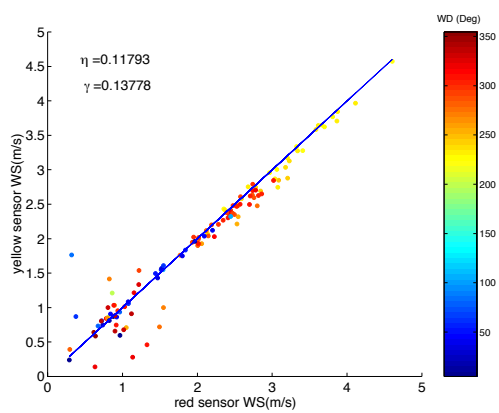


Wind Speed Comparison 11/16/2000 (afternoon and night)

Orange Sensor Cross Correlation

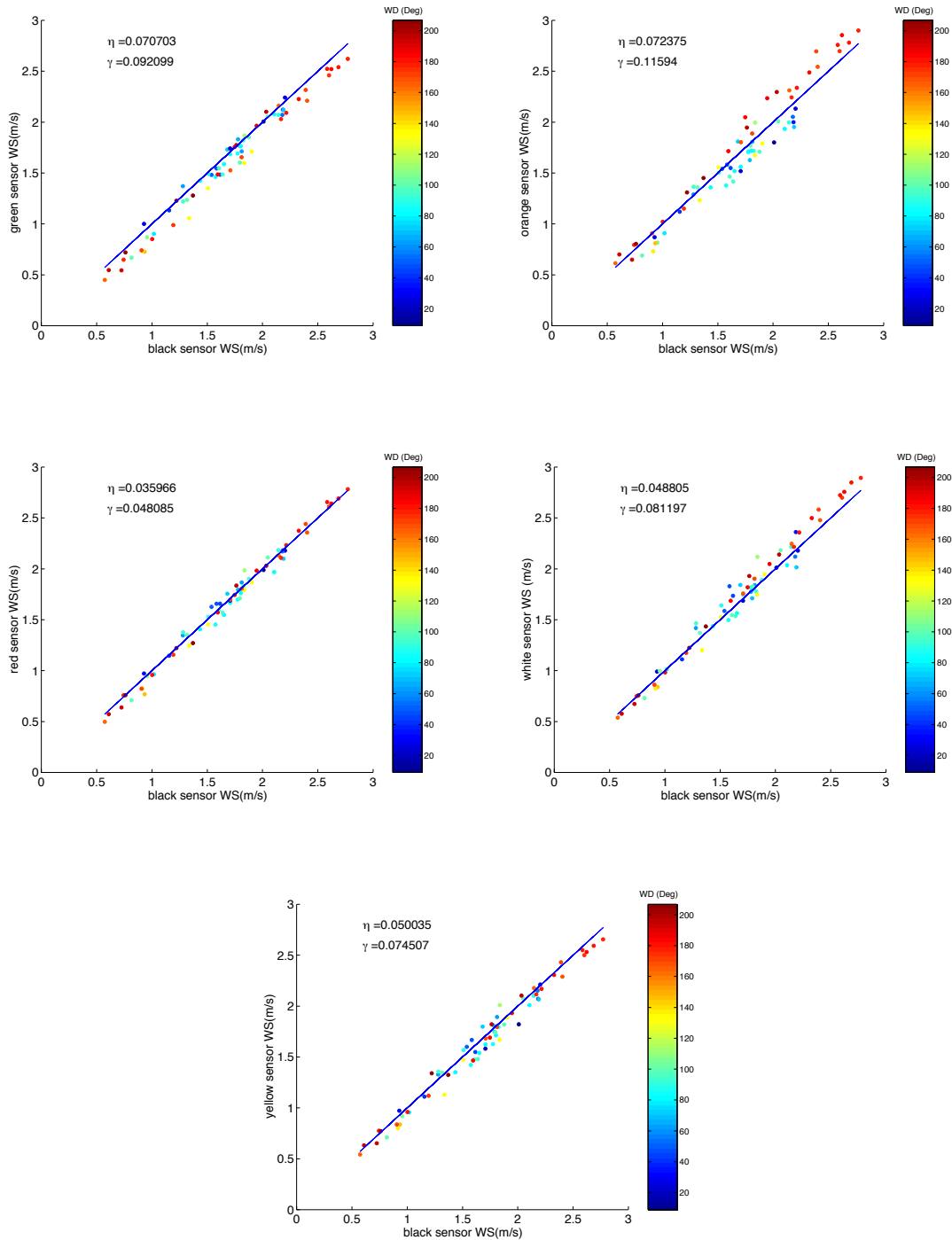


Red Sensor Cross Correlation



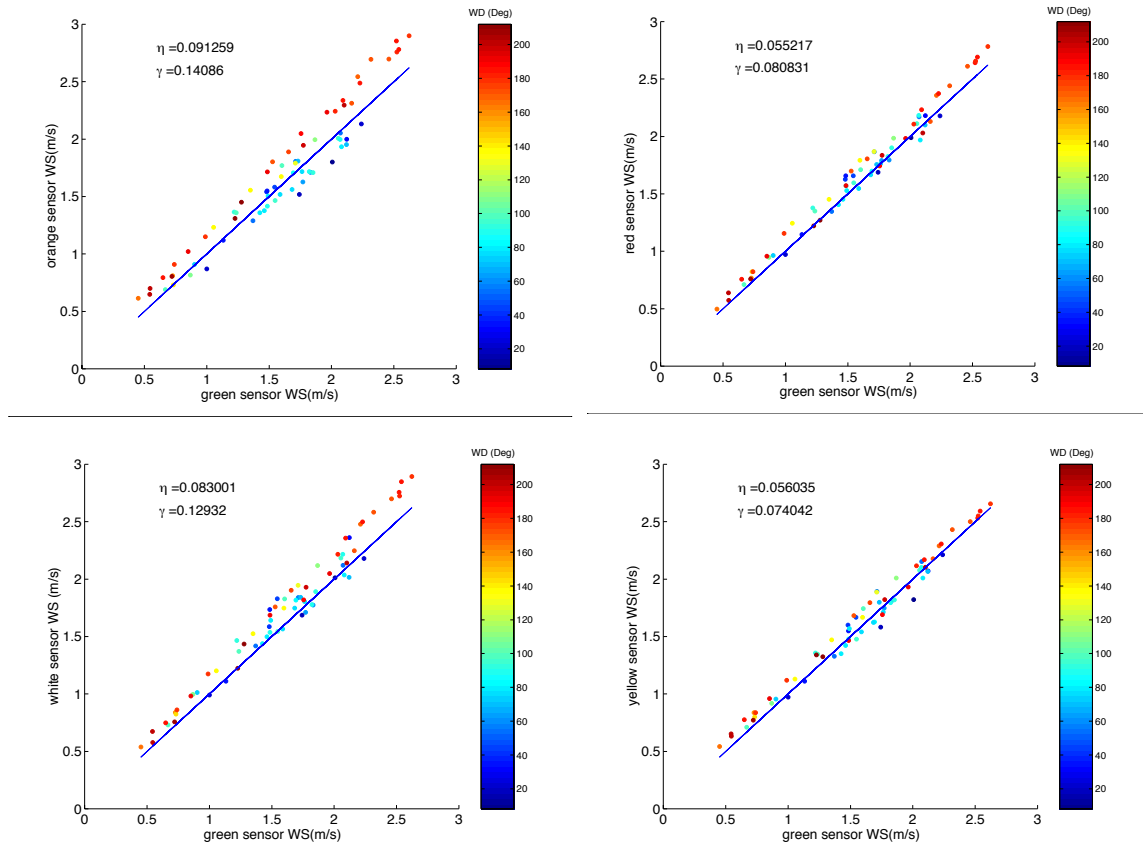
Wind Speed Comparison 11/21/2000 (morning & afternoon)

Black Sensor Cross Correlation

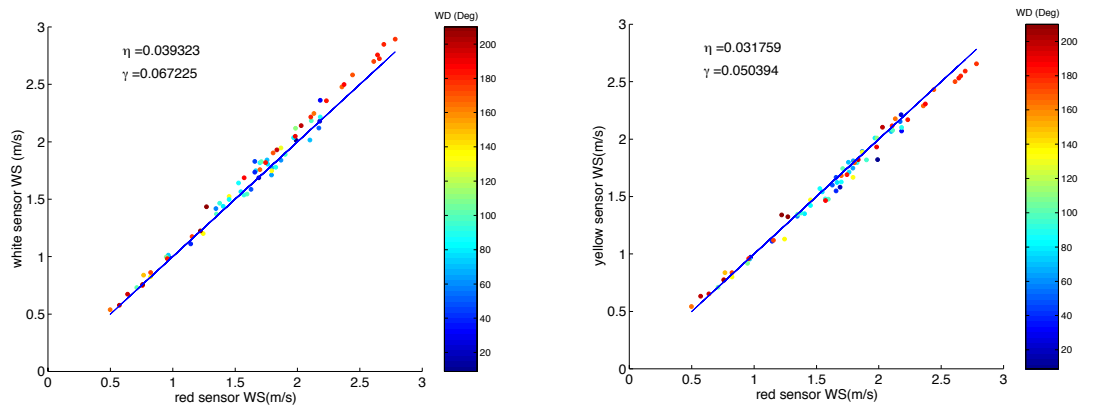


Wind Speed Comparison 11/21/2000 (morning & afternoon)

Green Sensor Cross Correlation

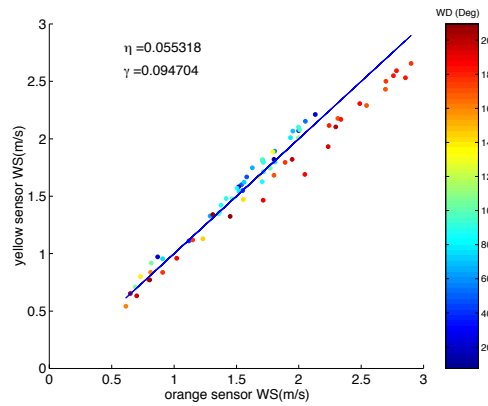
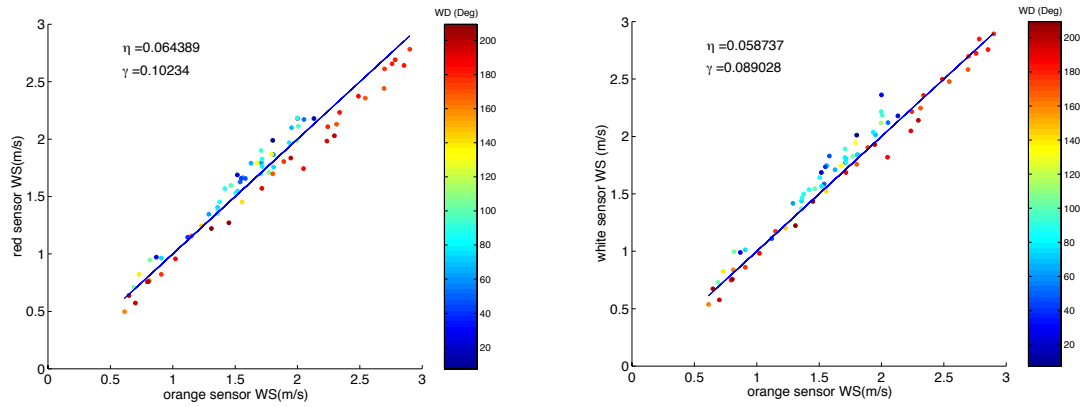


Red Sensor Cross Correlation

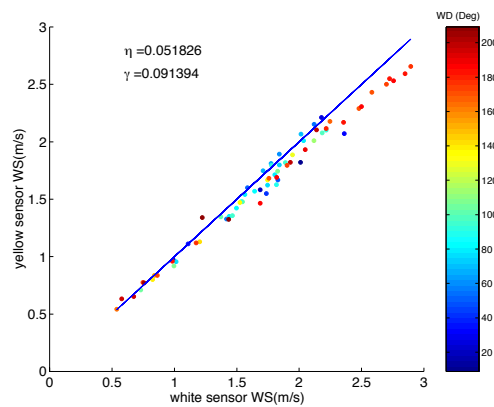


Wind Speed Comparison 11/21/2000 (morning & afternoon)

Orange Sensor Cross Correlation

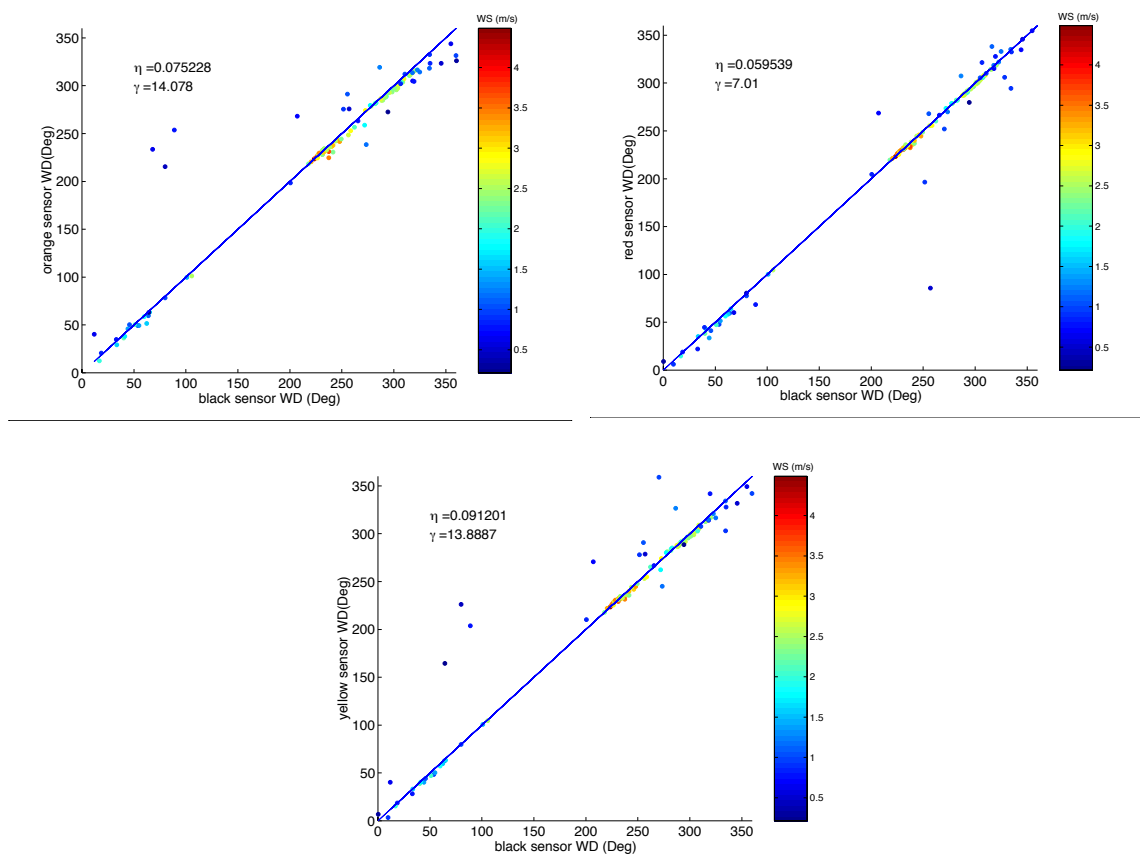


White Sensor Cross Correlation



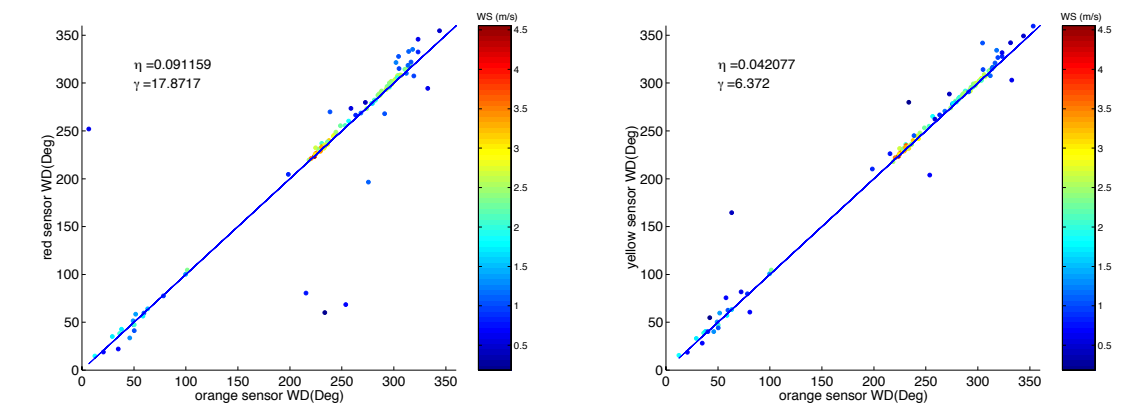
Wind Direction Comparison 11/16/2000 (afternoon and night)

Black Sensor Cross Correlation

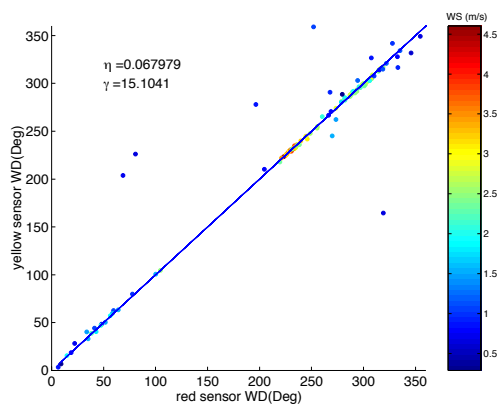


Wind Direction Comparison 11/16/2000 (afternoon and night)

Orange Sensor Cross Correlation

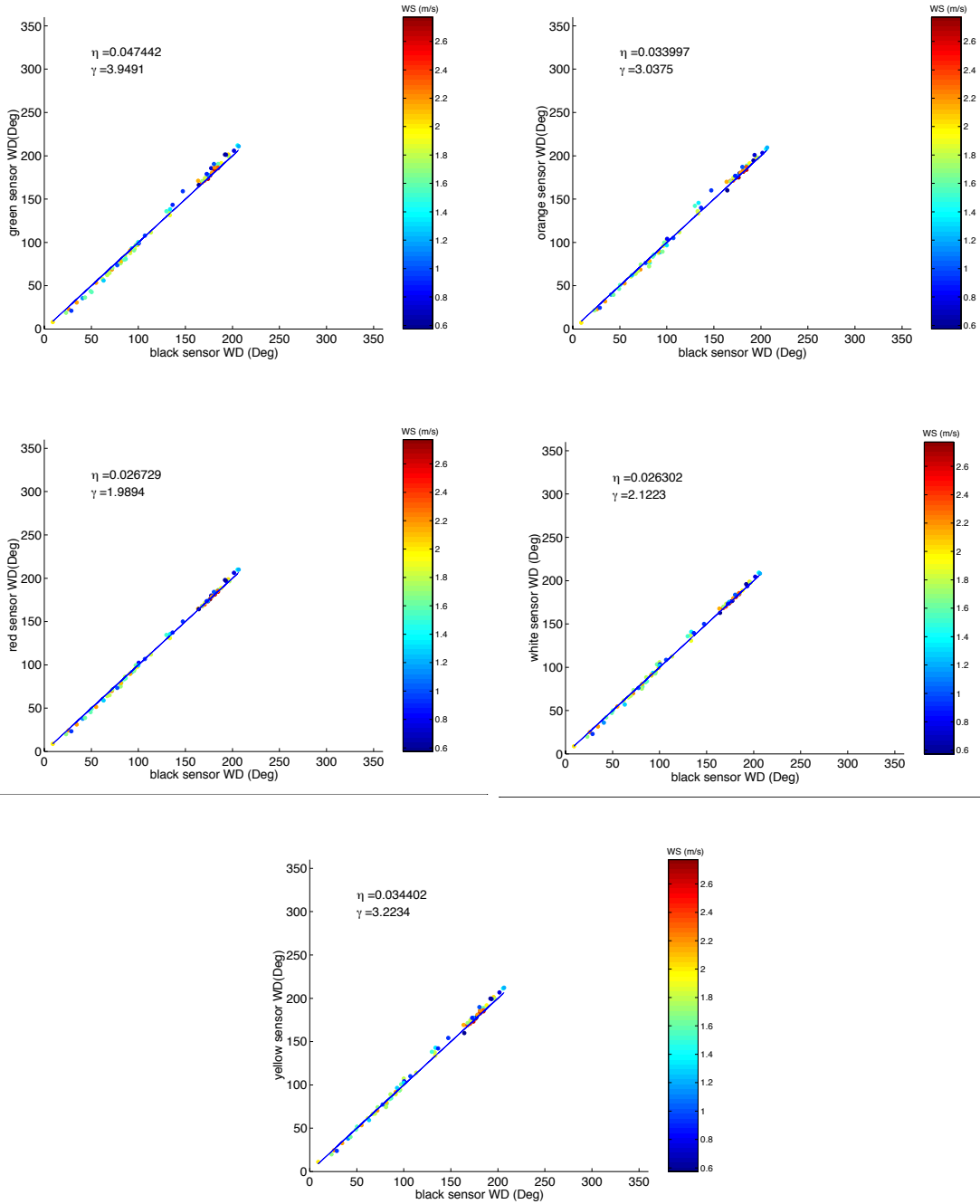


Red Sensor Cross Correlation



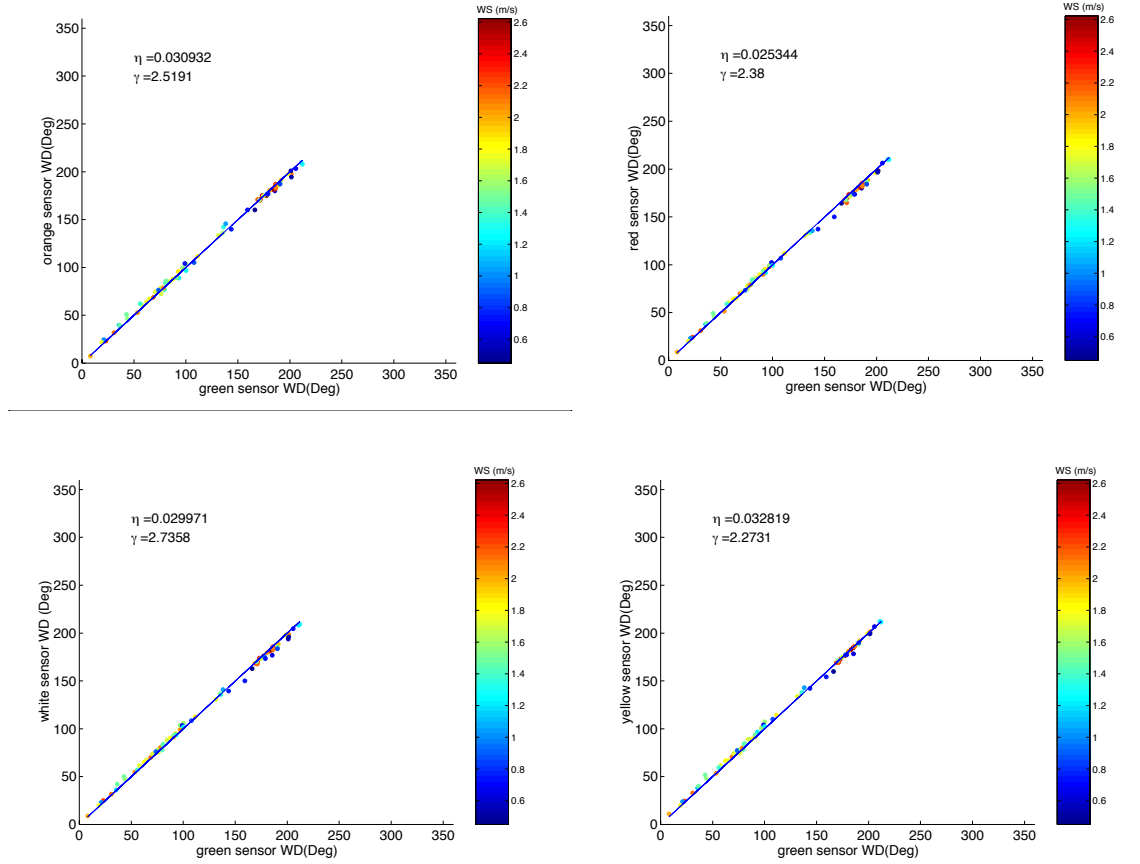
Wind Direction Comparison 11/21/2000 (morning & afternoon)

Black Sensor Cross Correlation

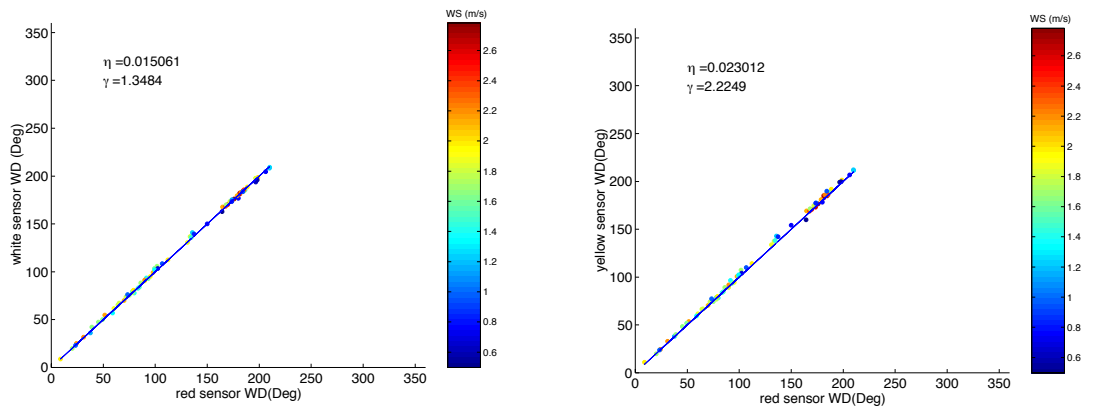


Wind Direction Comparison 11/21/2000 (morning & afternoon)

Green Sensor Cross Correlation

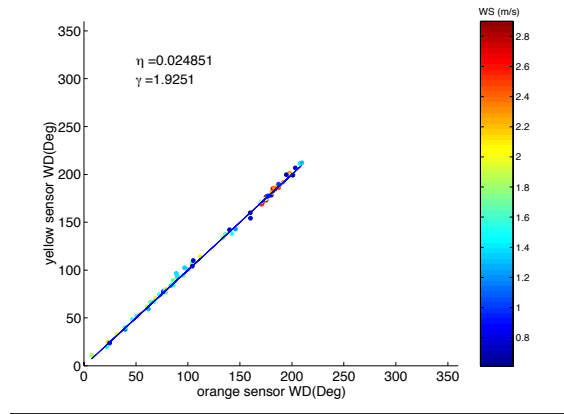
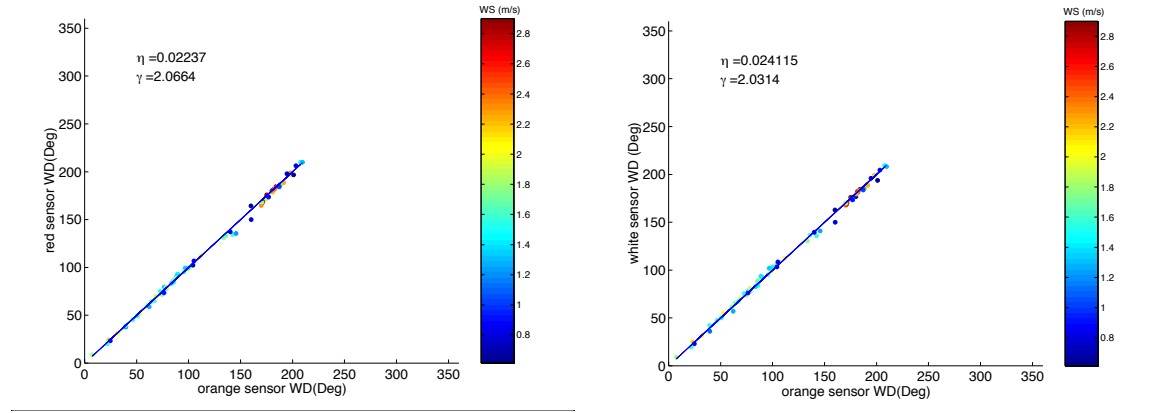


Red Sensor Cross Correlation

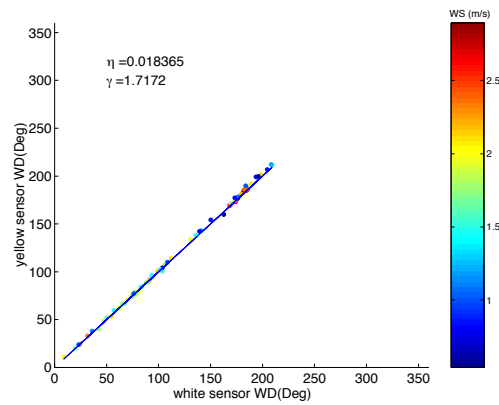


Wind Direction Comparison 11/21/2000 (morning & afternoon)

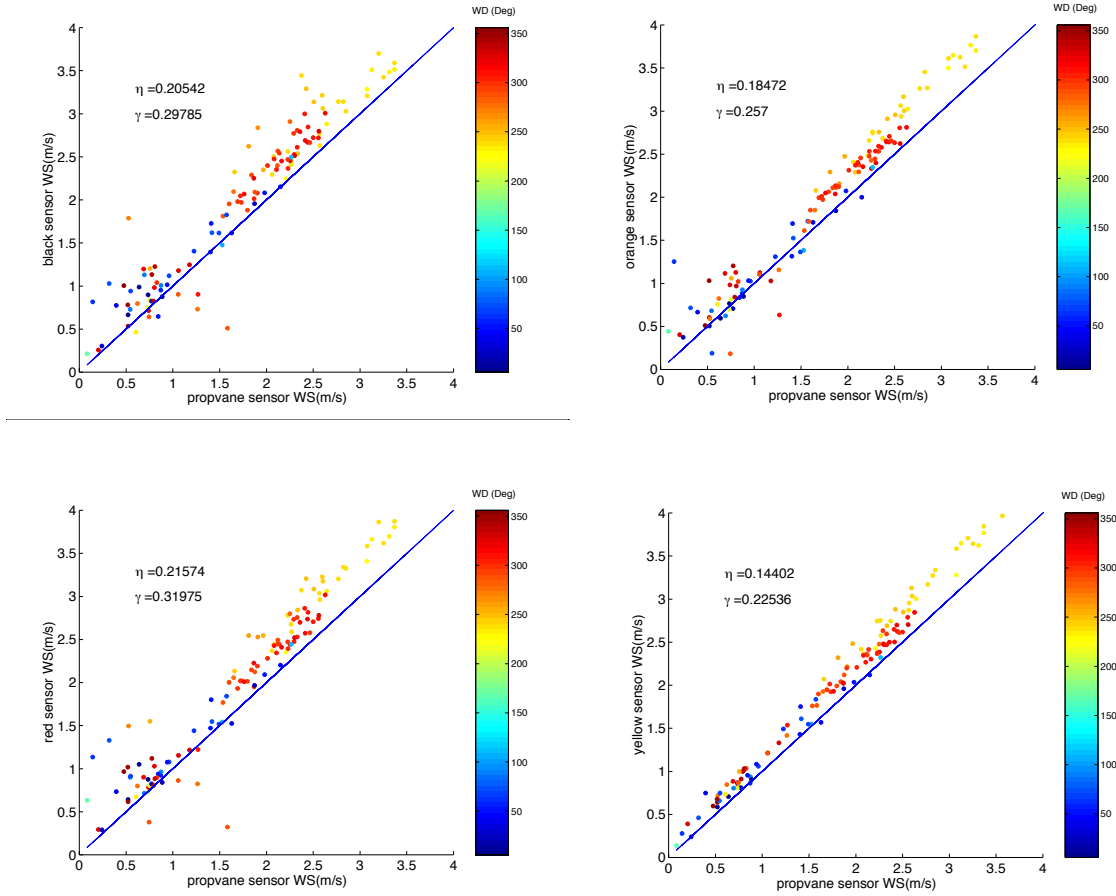
Orange Sensor Cross Correlation



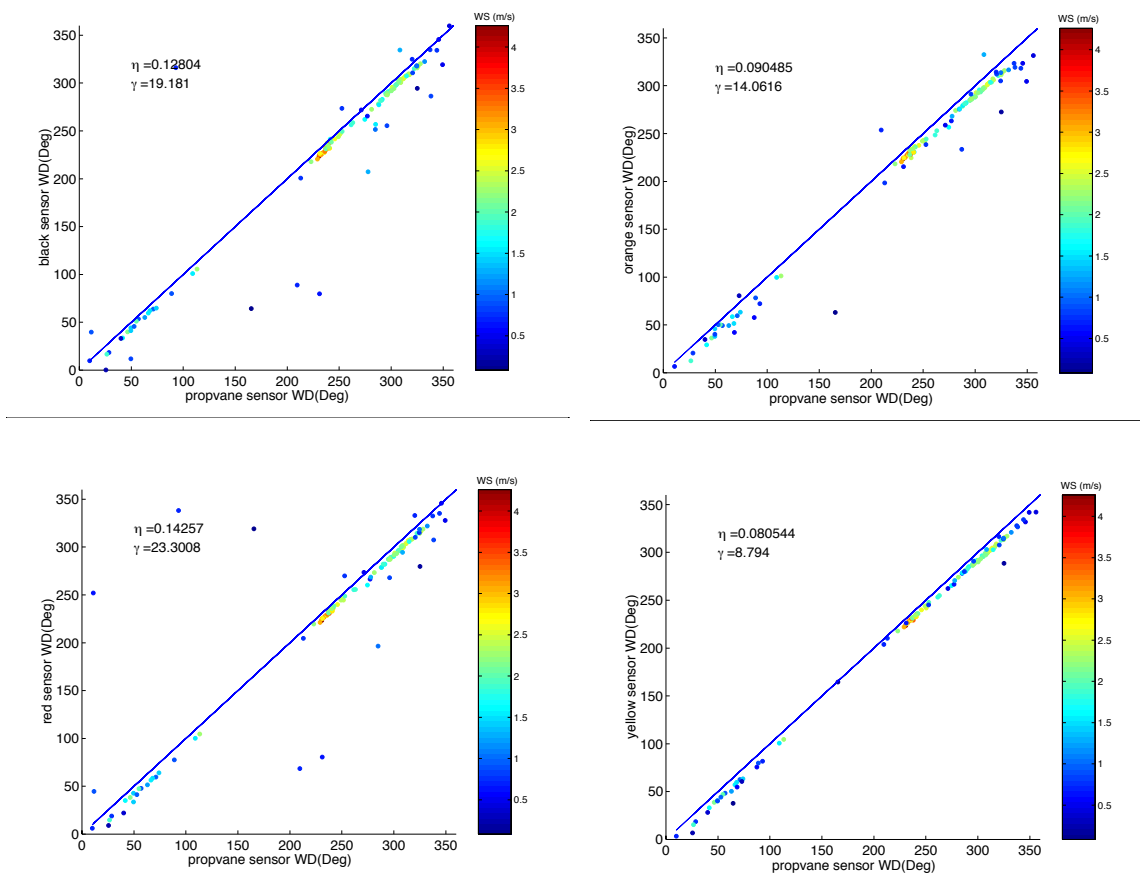
White Sensor Cross Correlation



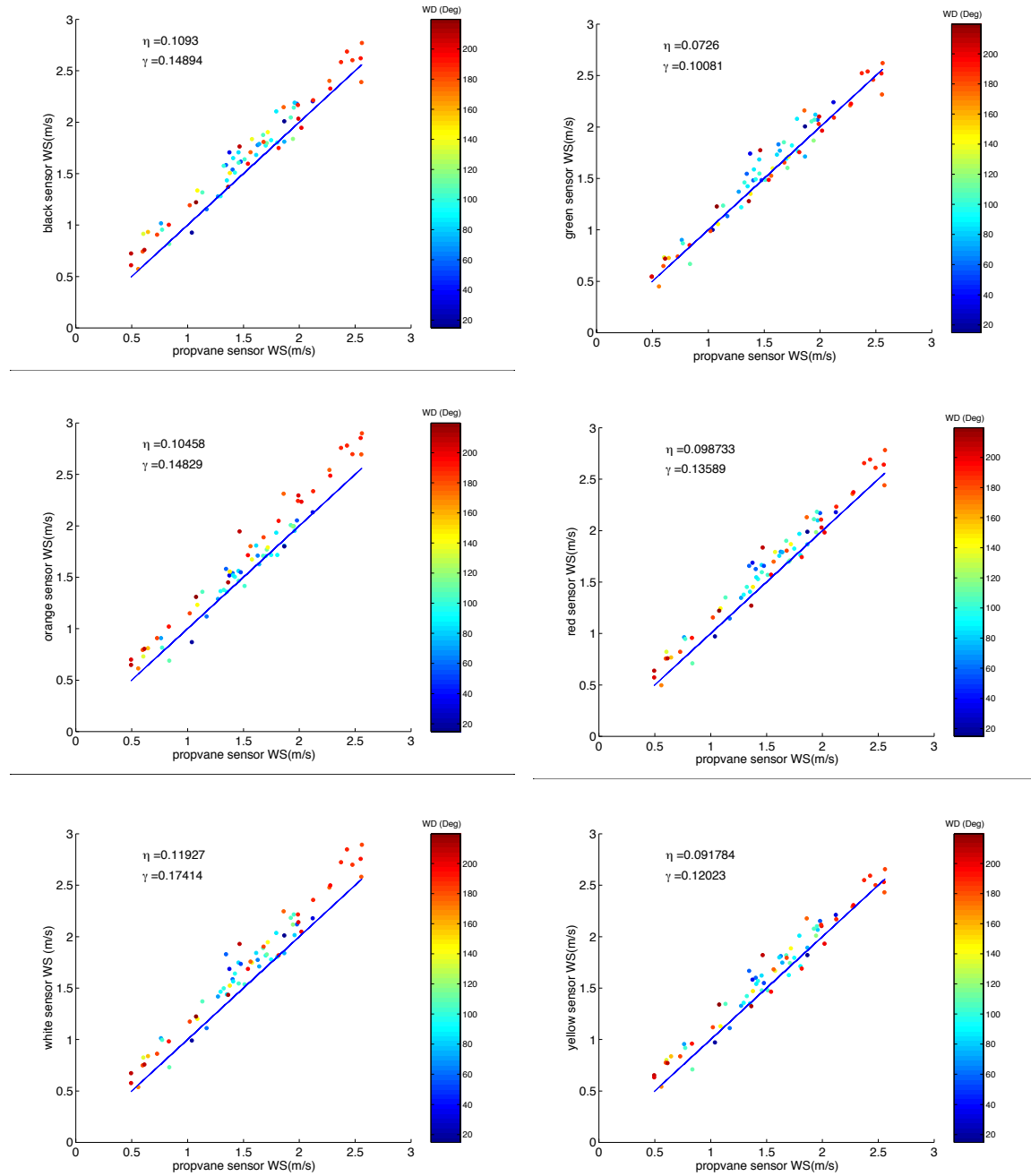
Propvane Wind Speed Comparison 11/16/2000



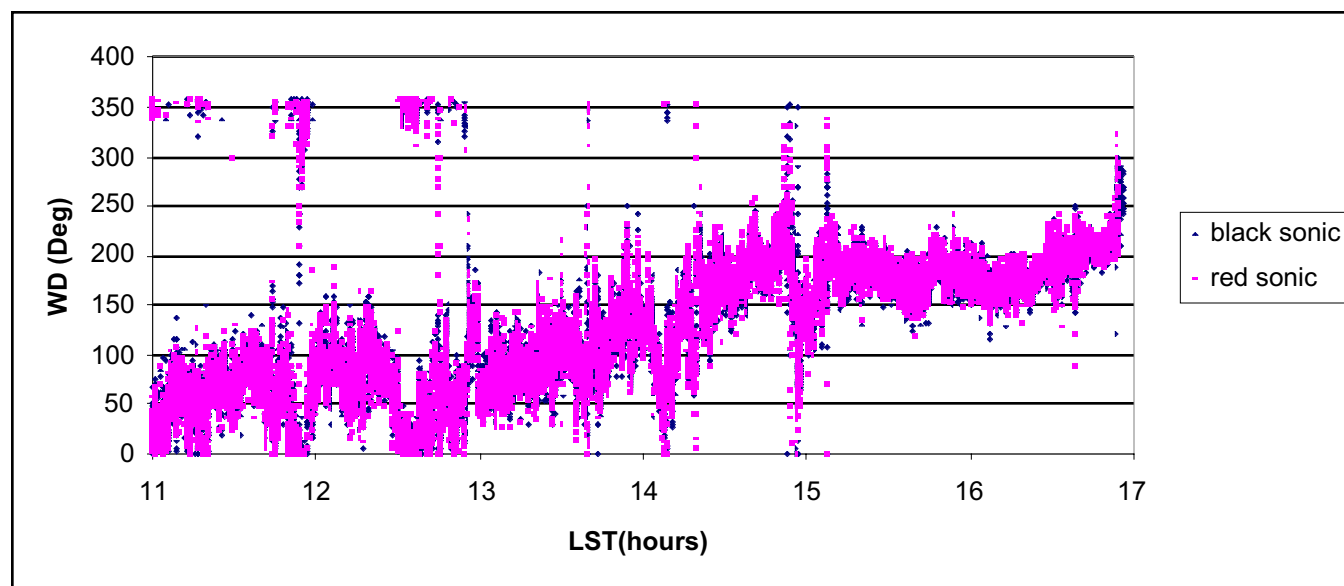
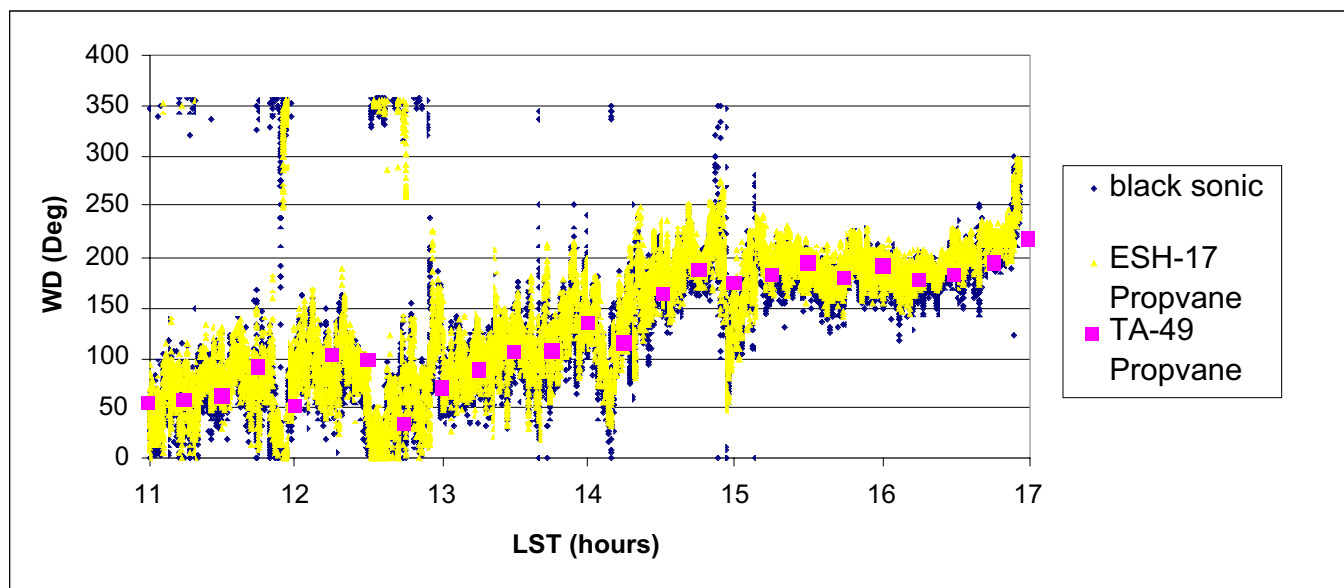
Propvane Wind Direction Comparison 11/16/2000



Propvane Wind Speed Comparison 11/21/2000



Time Series Comparison 11/21/2000



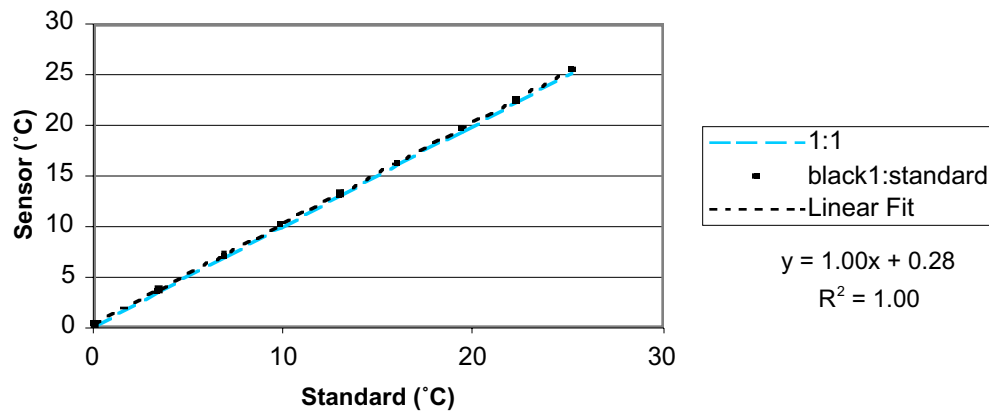
The DOE CBNP Salt Lake City URBAN Experiment of October 2000

LANL Urban Wind and Temperature Measurements Data Report

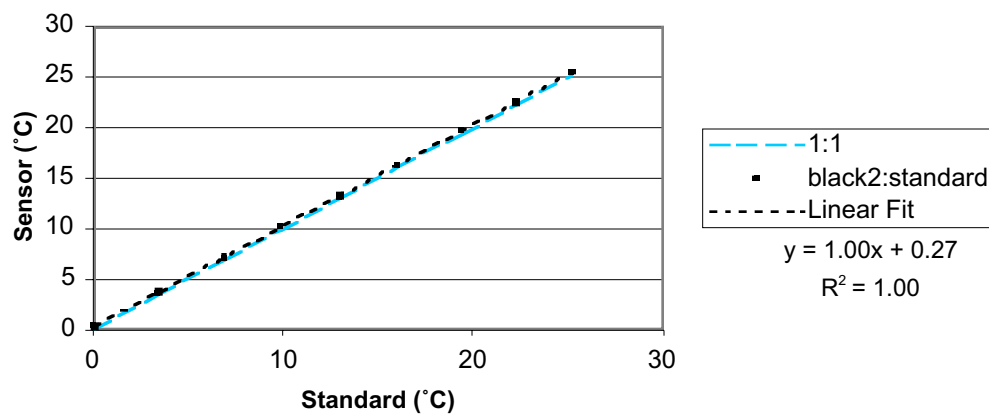
Appendix B: Thermistor Calibration Data Plots

Water Bath Temperature Calibration Data Plots (January 24, 2001)

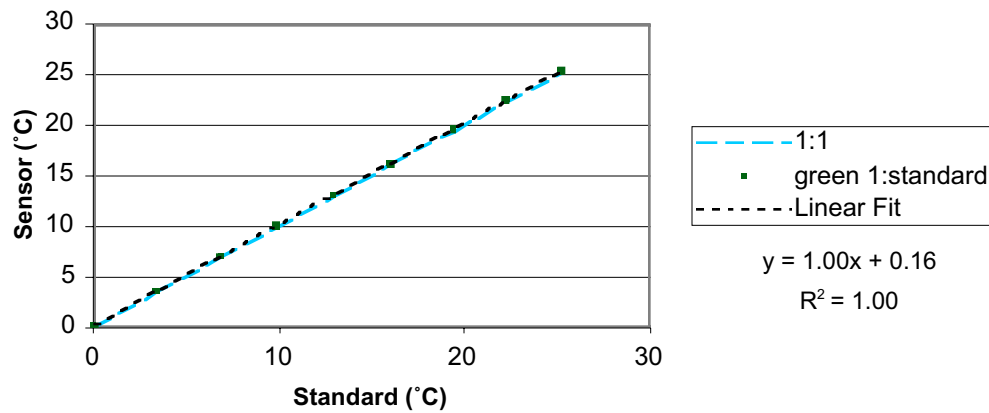
Temperature Calibration Black Unit - Sensor 1



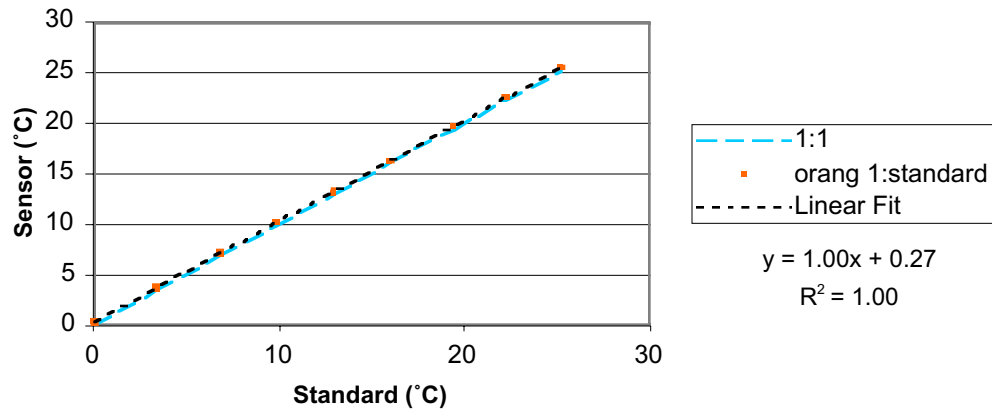
Temperature Calibration Black Unit - Sensor 2



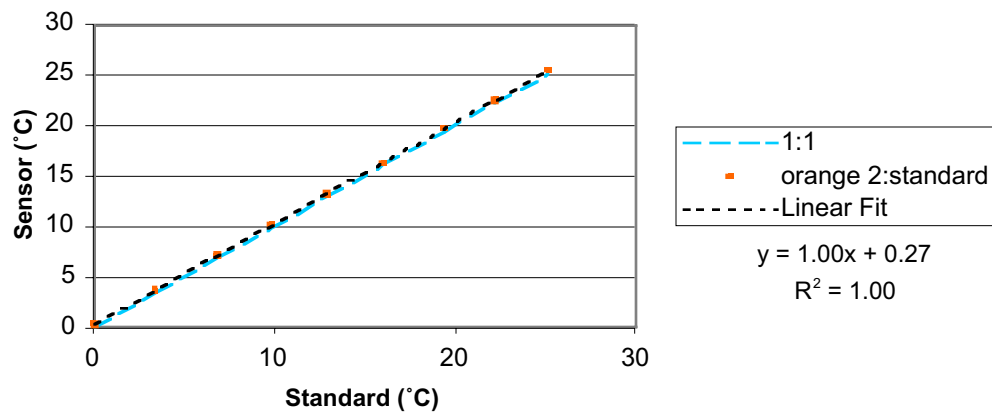
Temperature Calibration Green Unit - Sensor 1



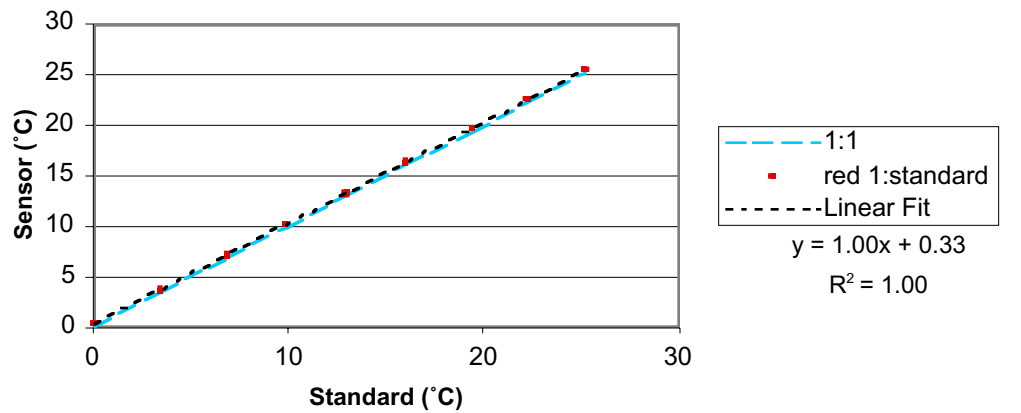
Temperature Calibration Orange Unit - Sensor 1



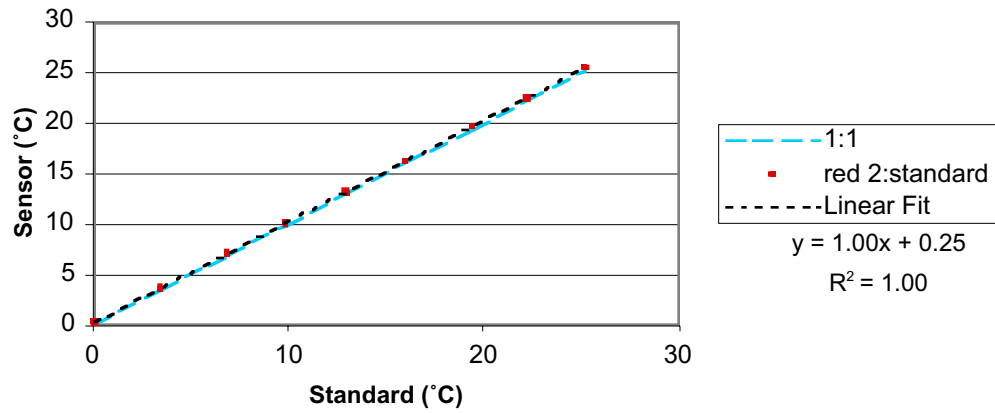
Temperature Calibration Orange Unit - Sensor 2



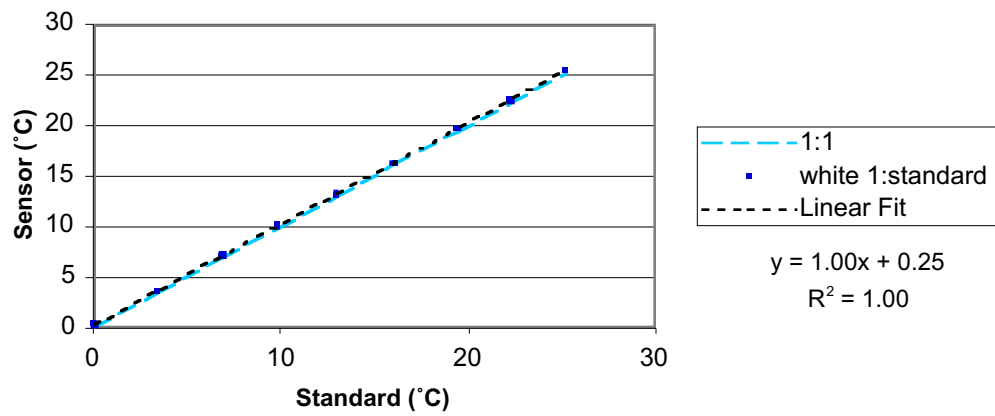
Temperature Calibration Red Unit - Sensor 1



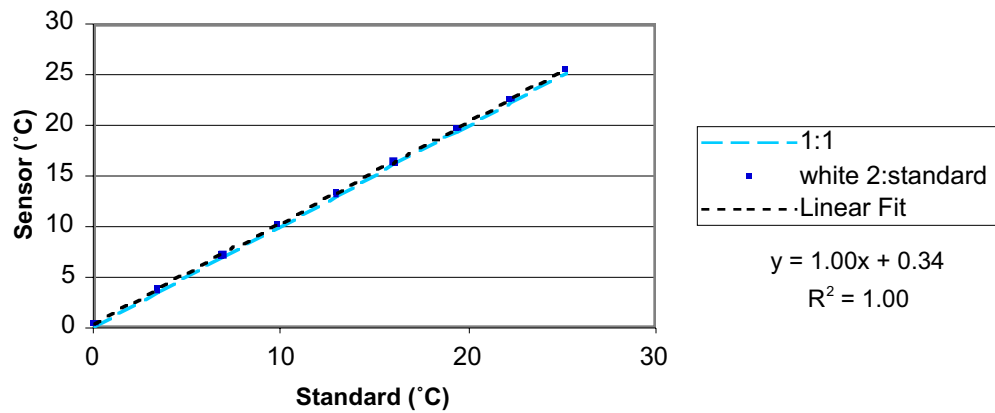
Temperature Calibration Red Unit - Sensor 2



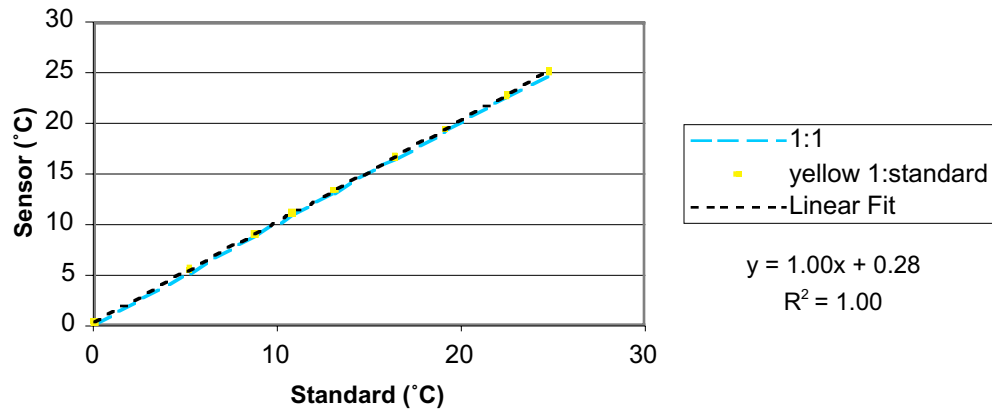
Temperature Calibration White Unit - Sensor 1



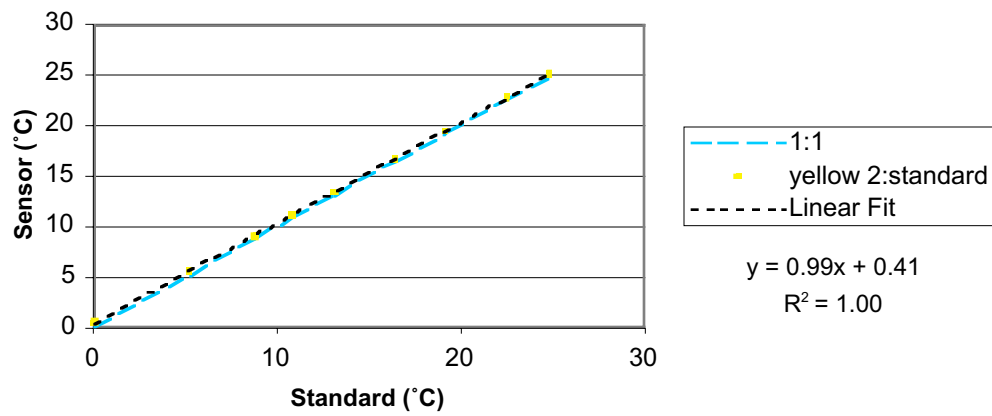
Temperature Calibration White Unit - Sensor 2



Temperature Calibration Yellow Unit - Sensor 1

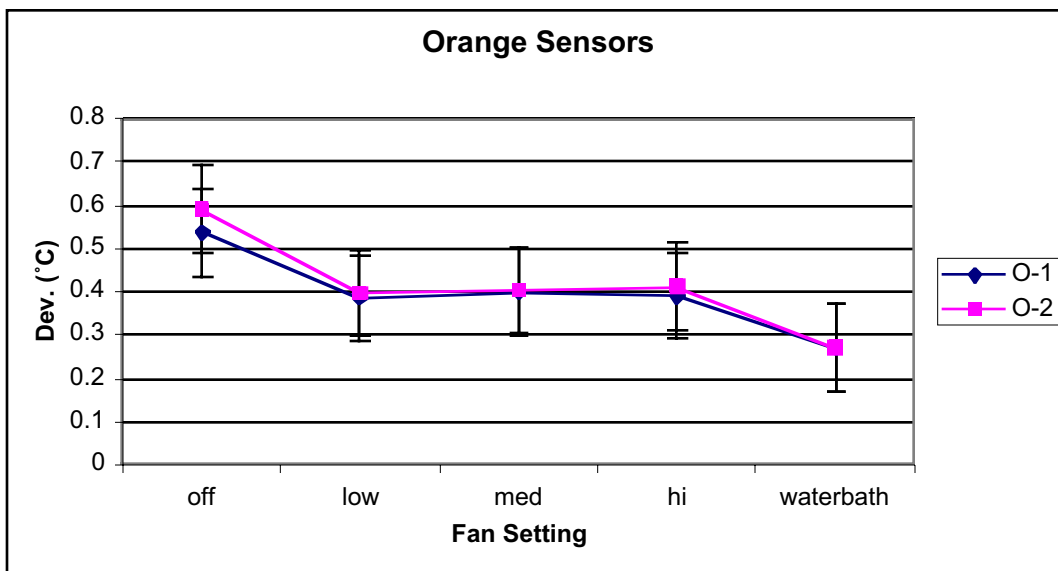
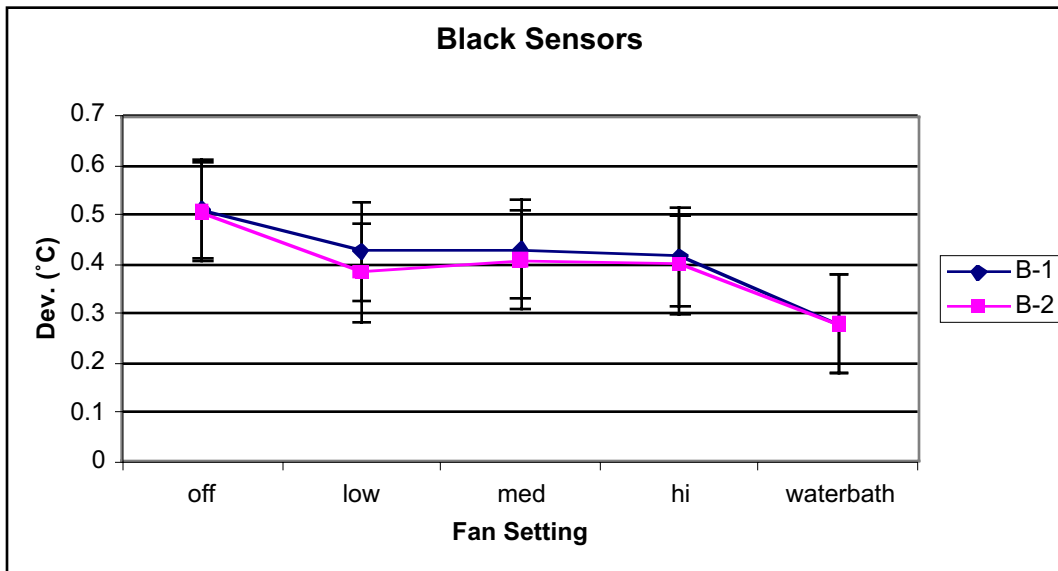
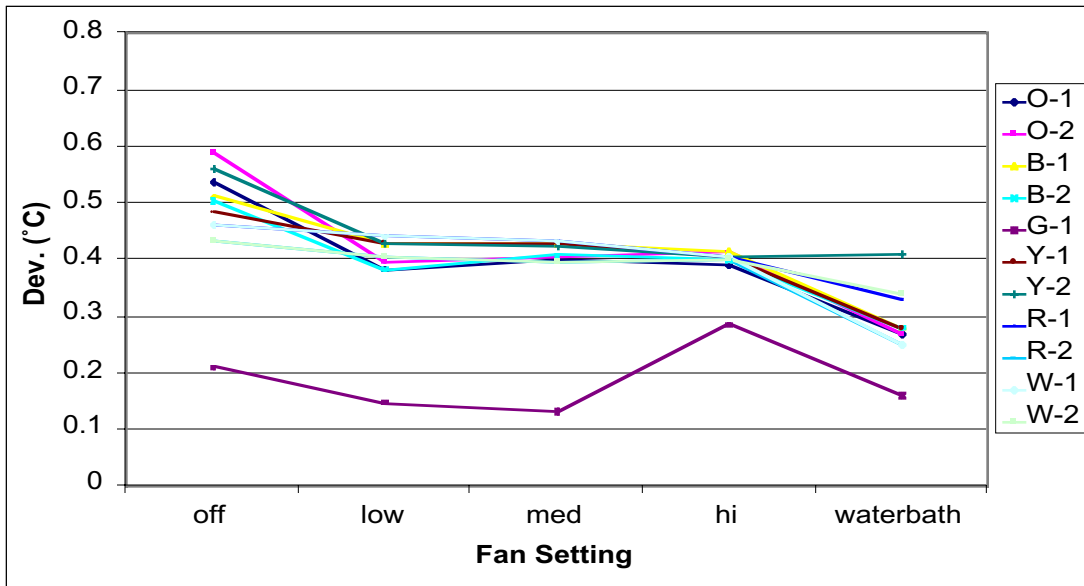


Temperature Calibration Yellow Unit - Sensor 2



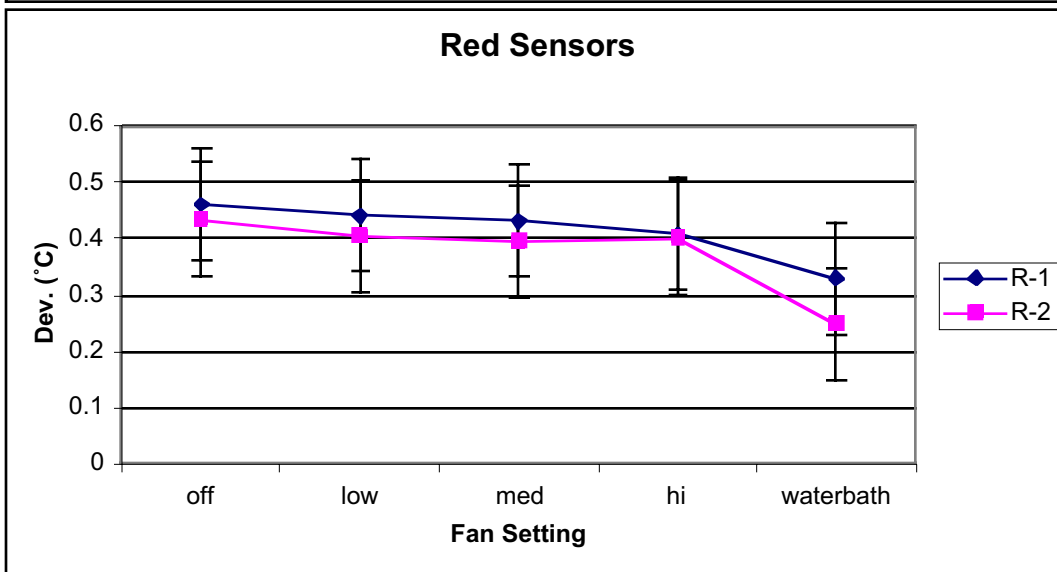
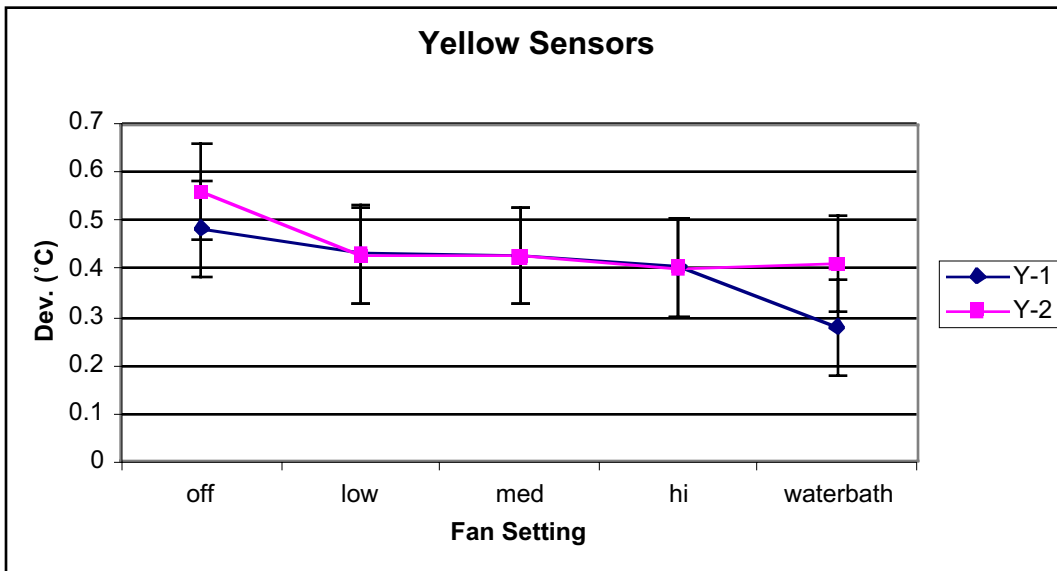
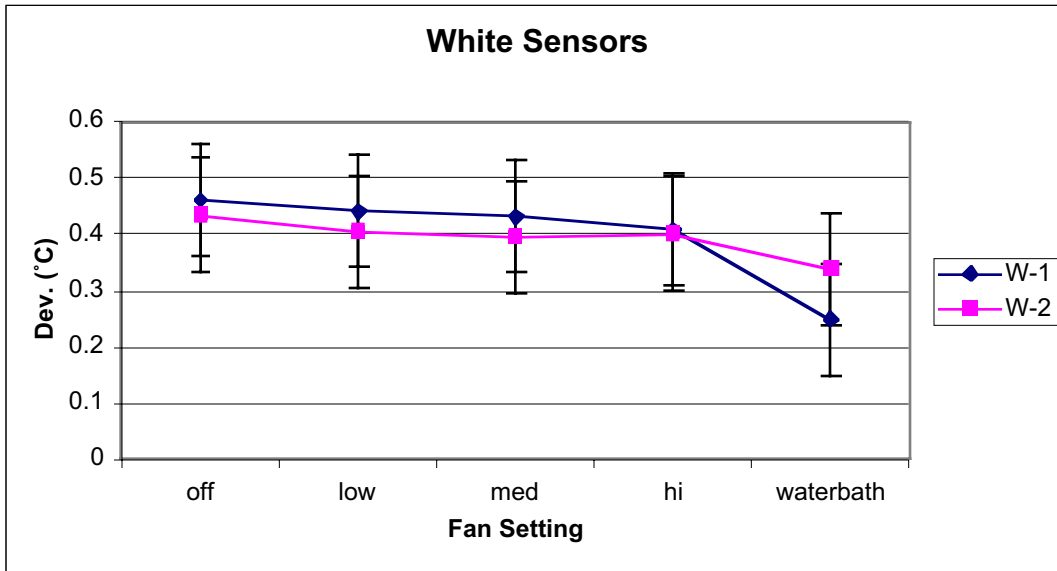
Deviation From Standard for Various Heat Transfer Coefficients

(Air measurements were taken at ~22 °C and waterbath data was taken over the range 0-25 °C)



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